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SULPHIDE TAILINGS MANAGEMENT STUDY

A Joint Project of
Monenco Limited, Cominco Limited, Inco Limited
and Ncranda Inc.

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CANMET, Mineral Science Laboratories
555 Booth Street
Ottawa, Ontario
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Dear Mr. Joe:

Re: Tailings Management Study - Final Report

We are pleased to submit this final report following your review of the draft.

We trust the report will assist you in your further efforts concerning the management of sulphide tailings.

Yours very truly,

Keith D. Phinney

K.D. Phinney, P.Eng.
Project Manager

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SUMMARY

The objective of this study has been to define the measures that are required to resolve the concerns and difficulties associated with the long term management of acid generating sulphide tailings.

Disposal sites containing acid generating sulphide tailings are located throughout the base metal mining regions of Canada. Thus, New Brunswick, Quebec, Ontario, Manitoba, British Columbia, and the Yukon and Northwest Territories contain deposits of tailings which generate acidic, metals containing effluents. Most of the tailings deposits, which range in areal extent from a few hectares to over a 1000 hectares, are located in surface impoundments formed by the construction of dams. Fewer of the deposits are located in lakes and offshore (British Columbia) areas.

During the past 20 years or so, the mining industry has implemented reclamation measures to return minesites to an acceptable state following the completion of mining activities. However, acid generating sulphide tailings present a very difficult and somewhat unique situation as regards to the achievement of reclamation requirements. The generation of acid within the tailings deposits not only inhibits the growth of vegetation on the deposits but may also continue to produce acidic, metals containing effluents, long after cessation of mining activities. At this time, there are many uncertainties as to whether or not many of the base metal minesites can be reclaimed so as to allow for their abandonment with no further obligations to the owner or society in general.

It has been well established that the formation of acidic conditions is due primarily to the oxidation of the ferrous sulphide minerals contained by sulphide tailings. These minerals, principally pyrite (FeS_2) and pyrrhotite ($\text{Fe}_{1-0.8}\text{S}$), are often associated with base metal orebodies. The formation of acidic conditions requires exposure of the minerals to oxygen (air) and moisture, and is enhanced by the

presence of certain microorganisms. The inhibition of the acid generation process has proven to be extremely difficult despite years of research and costly reclamation measures.

To date, reclamation measures have concentrated on the establishment of vegetation on tailings. It is apparent that successful site specific revegetation techniques have been developed during the past few years after many years of research. However, revegetation can be prohibitively expensive and, most importantly, it has not been established that revegetation of acid generating tailings will adequately inhibit the generation of acidic, metals containing effluents. Possibly the most effective inhibition of acid formation has occurred for those cases in which sulphide tailings have been disposed of underwater. However, this is not a practicable method in all cases and, in any event, may not be permissible due to regulatory requirements.

Further research and development programs are required to develop technology for the long term management of acid generating tailings. There is a need to better understand the physical and chemical processes that occur within sulphide tailings disposed of under various field conditions. A better understanding of these processes will enable the development of more effective methods for the planning of sulphide mining operations and for the disposal of acid generating tailings.

It is estimated that a 3 to 5 year development program would cost in the order of \$2.5 million, not including the cost of services that would be provided by the mining companies. This development program would include the following activities:

1. Technology transfer to ensure that information concerning well established technologies is available to the mining industry (revegetation, current tailings disposal, and effluent control practices)
2. Development of prediction techniques related to the

physical and chemical behaviour of tailings

3. Development of more effective methods for the disposal of tailings
4. Development of methods to inhibit and control the generation of acidity, and
5. Assessment of the specific benefits and effects of revegetation as an inhibitor of acid generation.

PART ONE
GENERAL INTRODUCTION

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1.0 GENERAL INTRODUCTION

The primary objective of this study is to define the measures that are required to resolve the concerns and difficulties associated with the long-term management of acid generating sulphide tailings. The definition of the required measures will be used to plan future research and other programs that are necessary to minimize if not eliminate the effect of acid generating tailings on the environment. To meet this primary objective, the study has reviewed the extent of acid generating tailings deposits within the various sulphide mining regions of Canada, reviewed the status of current tailings management practices, reviewed the state of knowledge concerning the generation of acid within sulphide tailings, and considered current practices for the treatment of acidic drainages resulting from acid generation. It should be noted that other sources of acidic discharges, in particular minewater and drainage from site contamination, have not been considered during this study.

Each of the mining companies involved directly in the study (Cominco, Inco and Noranda) has provided information relevant to meeting the objectives of the study. This information is available as separate appendices to the report.

During the past 20 years or so the mining industry has implemented waste management measures consistent with protection of the environment. During this same period, the need for reclamation measures to return the minesite to an acceptable state following the completion of mining activities has been recognized by the mining industry and regulatory agencies. Every province and territory in Canada currently requires that reclamation measures be implemented in order to return formerly mined lands to an "acceptable condition". Thus, despite the economic difficulties faced by the mining industry, considerable efforts have been made to develop technology and implement reclamation measures. Further development of cost effective measures are required to enable long-term planning for the eventual closure of existing and future sulphide mining operations.

Acid generating sulphide tailings present a very difficult and somewhat unique situation as regards to the achievement of reclamation requirements. The generation of acid within the tailings deposit not only inhibits growth of vegetation on the deposit but may also result in acidic metals containing seepages and drainages which may have adverse effects on the receiving environment. During the active mining phase the normal waste management practices prevent the discharge of acidic effluents. However, the implications of the potential for acid generation following the completion of the active mining phase are far-reaching, economically and environmentally.

Economic implications arise from the considerable costs that may be incurred in attempts to "rehabilitate" a minesite so as to allow for its eventual abandonment without any further liabilities to the owner or society. Successful reclamation in the case of those base metal mines, which are characterized by acid generating ores, wastes and mine workings (acid mine water), centres on reducing the discharges of acidic seepages and drainages to an "acceptable" level. An acceptable level of reduction is that specified by regulatory agencies or otherwise regarded as consistent with protection of the environment. At this time, there are many uncertainties as to whether or not many of the base metal minesites can be reclaimed so as to allow for their abandonment with no further obligations to the owner or society in general. These uncertainties arise from the difficulties that have been experienced in reclaiming minesites and from the lack of a methodology for confidently designing reclamation measures and forecasting their cost and effectiveness.

These concerns have provided the impetus for this study which will hopefully lead to the further developments necessary to satisfactorily enable the reclamation and eventual abandonment of mining properties associated with acid generating tailings.

PART TWO

THE EXTENT OF SULPHIDE TAILINGS IN CANADA

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2.0 EXTENT OF SULPHIDE TAILINGS

Acid generating sulphide tailings are found throughout the base metal mining regions in Canada. Base metal mining regions considered in this study are shown in Figure 2-1. Known deposits of sulphide tailings, due to current or recently completed mining activities, based on information provided by federal and provincial environmental agencies, are shown in Figure 2-2. The sites are identified in Appendix A. A list of major deposits of sulphide tailings are given in Table 2-1. A summation of areal extents reported for the various sites indicates that sulphide tailings deposits in Canada occupy an area in the order of 9000 ha. Informal discussions with the regulatory agencies indicate that there are also many relatively small deposits of tailings which have been abandoned for many years. Many of these deposits could be a valuable source of information concerning the natural "ageing" of sulphide tailings.

A majority of acid generating sulphide tailings deposits are located in on-surface impoundments formed by the construction of dams. The dams are commonly constructed of tailings, although borrow materials have been used at some minesites. Sulphide tailings deposits are also located in lakes and offshore areas (British Columbia), but this method of disposal has and continues to be used only to a limited extent. Tailings disposal practices are reviewed in Section 3.

FIGURE 2-1
BASE METAL MINING
LOCATIONS

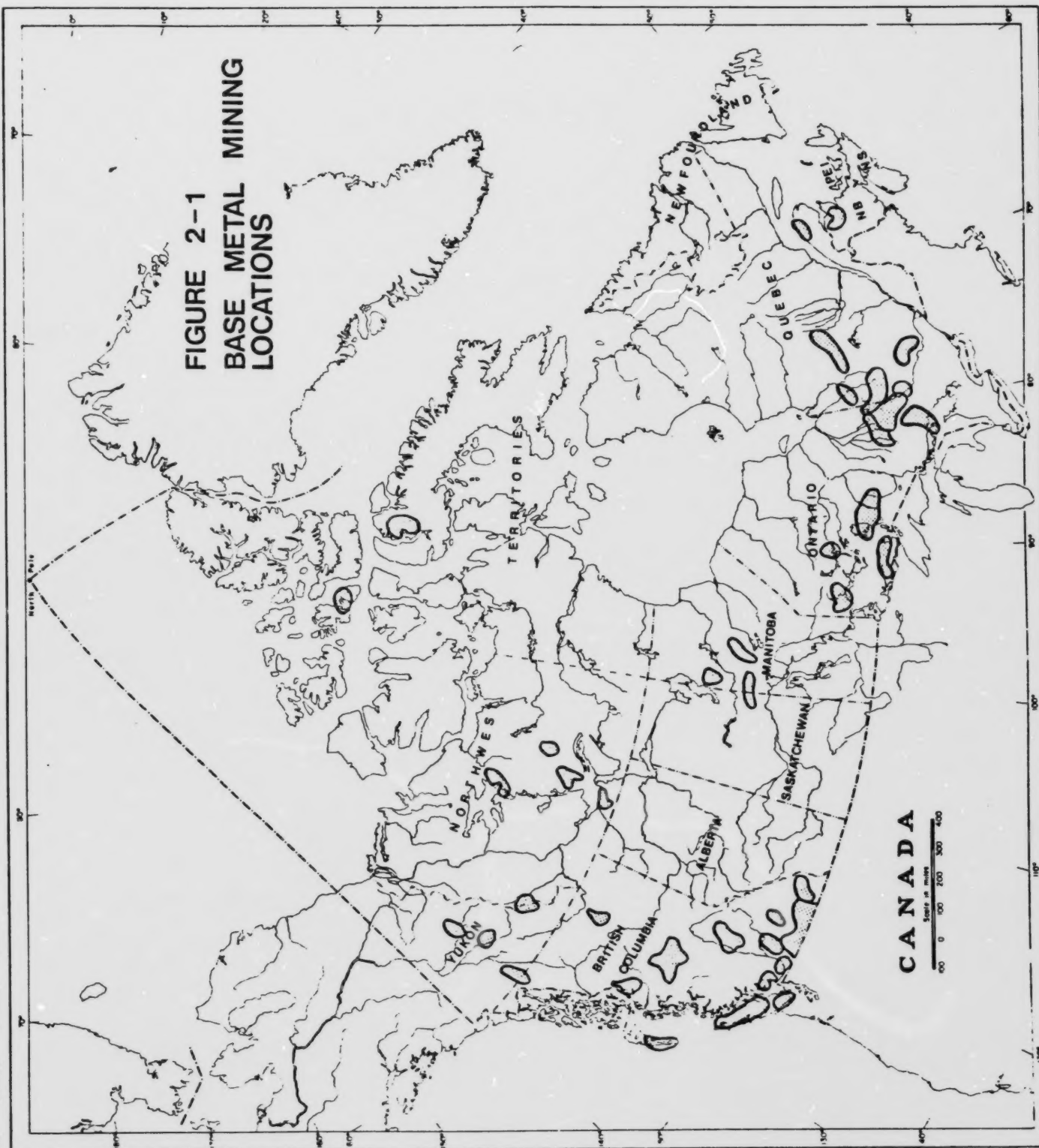


FIGURE 2-2
SULPHIDE TAILINGS SITES
 (Refer to Appendix A for
 identification of sites)

The map displays the geographical distribution of sulphide tailings sites across Canada. Sites are marked with dots and labeled with names such as 'Mackenzie', 'Edmonton', 'Winnipeg', 'Toronto', 'Montreal', 'Ottawa', 'Quebec', 'Halifax', 'St. John's', 'Vancouver', 'Calgary', 'Edmonton', 'Winnipeg', 'Toronto', 'Montreal', 'Ottawa', 'Quebec', 'Halifax', 'St. John's'. The map also shows the Arctic Ocean to the north, the Atlantic Ocean to the east, and the Pacific Ocean to the west. The map is oriented with North at the top, and the Atlantic Ocean is to the east and the Pacific Ocean to the west.

TABLE 2-1
Some Major Sulphide Tailings Deposits

Mine Name/Location	Reference No. (Figure 2-2)	Mine Status	Sulphide Tailings Disposal
<u>New Brunswick</u>			
Brunswick Mining	1	In operation since 1964, expects to operate at least to 2005	607 ha tailings disposal area, dams are constructed of tailings, some revegetation trials, massive sulphide tailings, highly acid generating
Heath Steele Mines	2	In operation 1955-1958 and 1962 to 1983, closed, future uncertain	202 ha tailings disposal area, borrow material dam, some revegetation trails, massive sulphide tailings
<u>Quebec</u>			
Campbell Resources Ltd.	3	In operation since 1955	138 ha tailings disposal area, revegetation is being attempted
Cedar Bay & Henderson Mines	6	In operation from 1938 to 1929	170 ha tailings disposal area has been revegetated
East Marlarctic Mines	7	In operation since 1964	77 ha tailings disposal area containing massive sulphides, revegetation test plots have been established
Falconbridge Copper	8	In operation since 1954	153 ha tailings disposal area formed by draining of lake
Falconbridge Copper	9	In operation since 1952	316 ha tailings disposal area
Noranda Murdockville	10	In operation since 1935, limited reserves remain	280 ha tailings disposal area, revegetation test plots
Lamaque Mines	14	In operation since 1963	200 ha tailings disposal area in drained lake, large scale revegetation tests, massive sulphide tailings
Matagami	18	In operation since 1957	126 ha tailings disposal area, some areas have been revegetated
<u>Ontario</u>			
Mattabi Mines	2	In operation since 1972	160 ha tailings disposal area
Sturgeon Lake	3	In operation since 1957	130 ha tailings disposal area
Geco Division, Noranda	4	In operation since 1966	1200 ha tailings disposal area, use cone discharge disposal method
Kidd Creek Mines	7	In operation since 1930s	2400 ha tailings disposal area, extensive areas of revegetation
Sudbury District Mines of Inco	8	In operation since 1930s	~70 ha tailings disposal areas, extensive areas of revegetation
Sudbury Area operation of Falconbridge Ltd.			
<u>Manitoba</u>			
Fox Mine - Sherritt Gordon	1	In operation 1970 to 1983	Tailings will be flooded to stabilize
Lynn Lake - Sherritt Gordon	2	In operation 1953 to 1976	125 ha tailings disposal area containing massive sulphides
Ruttan Mine - Sherritt Gordon	3	In operation since 1973	Tailings discharged into Ruttan Lake
Thompson Mine - Inco	4	In operation since 1960	1800 ha tailings disposal area containing massive sulphides
Stall Lake - HBMS	5	In operation since 1964	Tailings discharged into Anderson Lake (365 ha)
Anderson Lake Mine - HBMS	6	In operation since 1970	Tailings discharged into Anderson Lake (365 ha)
Flin Flon Mine - HBMS	7	In operation since 1970	230 ha tailings disposal area
<u>British Columbia</u>			
Sam Goosly	1	In operation since 1979	230 ha tailings disposal area, revegetation test plots have been established
Westmin Resources	2	In operation since 1975	Tailings discharged into Buttle Lake, tailings contain massive pyrite
Gibraltar Mines	4	In operation since 1972	533 ha tailings disposal area, small area has been reclaimed
Sullivan Mine - Cominco	11	In operation since 1910	370 ha tailings disposal area, very extensive revegetation research, refer Appendix D-20
<u>Yukon, NWT</u>			
Anvil Mine	2	In operation since 1969	23 ha tailings disposal area containing massive sulphides

PART THREE
CURRENT TAILINGS MANAGEMENT PRACTICES

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3.0 CURRENT TAILINGS MANAGEMENT PRACTICES

This section of the report reviews current practices for the disposal of sulphide tailings. The review is based primarily on information provided by Cominco, Inco and Noranda (Appendix B).

3.1 SULPHIDE TAILINGS

Tailings consist of that part of the ore which is rejected following the recovery of the economic minerals. The tailings, which may consist of 90% or more of the mined ore, are a solid waste which must be permanently disposed of. Normally, the tailings are transported as a slurry to a tailings impoundment area. In some cases tailings are disposed of into lakes and offshore areas.

Tailings consist of finely ground solids containing host rock, ferrous sulphides (pyrite, arsenopyrite, pyrrhotite, others) and at least traces of other basemetal sulphides. In some cases, the tailings are readily dewatered by natural draining, whereas in others the grind is very fine, resulting in slimes which tend to retain water and therefore do not dewater upon standing. The tailings may contain from only a few percent to over 70% of pyrite and other sulphides.

3.2 DISPOSAL SITES

Historically, the selection of tailings disposal sites has been concerned primarily with locating one or more areas of acceptable capacity near the mine site. Low cost was almost always the main criterion. This approach led in some cases to the uncontrolled release of tailings into watercourses and continued release of acidic drainages following completion of mining activities (Hawley, 1972). More recently environmental regulations and technical, legal and social constraints have introduced new variables to the site selection process. It is now no longer adequate to design

the tailings facilities solely for the storage of large quantities of solids. The design has to consider recycle of water, the treatment of effluents, dust control, aesthetics, and the rehabilitation of the disposal area at the conclusion of mining activities

Most provinces and the federal government now require extensive environmental impact studies, detailed tailings disposal, construction and operating plans, and in many cases, holding of public hearings before granting approval for the development of tailing disposal facilities. In some jurisdictions it is also necessary to post bonds to cover the cost of rehabilitation and maintenance of tailings at the termination of mining activities.

The changes in tailings disposal practices and the selection of ultimate disposal sites have also been influenced by the grade of ore deposits and changes in milling technology. With the depletion of high grade ore deposits, the average milling rates have increased to justify the development of lower grade deposits. This has meant that tailings are more voluminous.

321 FUNCTIONS

The tailings disposal area provides a location for the permanent storage of mill tailings. In addition, the tailings disposal area may be required to perform other functions such as:

- removal of suspended solids by sedimentation
- flow balancing of storm water flows
- equalization of wastewater compositions
- stabilization of oxidizable constituents such as

- thiosalts and flotation reagents, and
- precipitation of heavy metals as hydroxides.

Tailings are disposed of primarily in tailings ponds formed by the construction of impoundment dams. Tailings ponds have a number of inherent disadvantages due primarily to their relatively large surface area to storage volume ratio. The disposal areas are often very difficult to isolate from natural drainage areas. Drainage from neighbouring areas and from direct precipitation onto the pond can result in increased contaminant loadings to receiving streams. The large surface areas of most tailings areas are very detrimental to rehabilitation efforts.

322 SITE SELECTION

The selection of a suitable tailings disposal impoundment is normally carried out during the preliminary phases of mine/mill development. The search begins with a review of aerial photographs and large scale maps. A number of criteria must be taken into account during the selection process, these include:

- adequate capacity to impound the projected quantity of tailings to be produced during the life of the mine/mill operation
- proximity to the mill site to minimize tailings transportation distances
- location within the same watershed as the mine and mill and at a lower elevation compared to the process area to minimize, if not eliminate, pumping requirements
- location in an area of impermeable overburden, minimum groundwater flow, suitable subsurface geotechnical conditions for construction of dams and availability of construction materials
- minimum catchment area and ease of surface water diversion
- unobtrusive to the general public.

- an area that is capable of supporting an acceptable reclamation plan

Once the potential sites have been identified, reconnaissance is carried out to eliminate some sites, and to locate any others not previously noted. Eventually the most highly ranked site or the two best sites are selected for further environmental, technical and economic evaluation. The final selection represents an optimum choice between costs and minimization of effects on the environment.

In general, a site which offers a minimum catchment area, minimum groundwater flow, and which allows for adequate interception of surface runoff and collection of seepages offers the best potential site for eventual reclamation.

In some cases, it has not been practical to locate a site for tailings disposal by construction of an impoundment area on surface. In such cases, it may be possible to obtain authorization from the regulatory agencies to discharge tailings into a lake or other waterbody. This practice was much more prevalent in the past than at present (Hawley, 1975). However, disposal of tailings under water is still practiced (e.g. Hudson Bay Mining and Smelting (HBMS) operations at Flin Flon, Manitoba) and, as discussed in Section Four, may be beneficial with respect to the long term management (stabilization) of sulphide tailings (Fraser, 1978).

323 SITE DEVELOPMENT

Following selection of the tailings disposal site, detailed engineering studies and design are initiated. To a large extent, the approach adopted at a given mine/mill complex will depend on the subsurface conditions at the site, the availability of suitable borrow materials, and the feasibility of using tailings in the construction of the dam.

Suitable local material, is generally used to build the starter dam(s). Where the withdrawal of supernatant water from the tailings pond is by decant towers, the decant pipes are installed before the starter dam is constructed; the decant tower is then raised in stages during the lifetime of the operation. As mentioned previously, concentrator tailings are almost always used to raise the dam if they meet geotechnical criteria for dam construction.

3.3 CONTAINMENT STRUCTURES

In past, tailings dams were designed primarily to retain the solid fractions of the tailings. Starter dams were constructed of onsite material, mine rock, slag or coarse tailings. When necessary, the dams were incrementally raised using the coarse fraction of the tailings. As such, the dams were reasonably watertight with emphasis being placed on stability and containment. Uncontrolled seepage sometimes occurred, particularly at the interface of bedrock and tailings. Today's dams are constructed so as to meet stringent engineering criteria. Although the practices of using tailings as the construction material remains, much more emphasis is placed on geotechnical design of the dam and monitoring during the construction and operating phases.

The main factors which influence the design of tailings dams are:

- topography
- foundation conditions
- availability of dam building materials
- seepage control
- hydrologic conditions, and
- seismic conditions.

The design of tailings dams receives very careful consideration including the following:

- the bulk of material to be stored often consists of saturated slime sized solids
- the dam is often constructed of the tailings themselves due to economic considerations and often the shortage of suitable borrow materials, and
- the dam will be frequently raised during the lifetime of the mining operation.

The stability of the structure must be assured by providing adequate drainage facilities within the dam and foundation, stable side slopes, and adequate freeboard and discharge (decant and/or spillway) facilities.

Tailings dams may be constructed entirely or partly of borrow materials, or from the tailings themselves, assuming they are suitable for construction. In most cases, the dams are constructed of tailings due to economic considerations. Dams constructed of tailings are normally constructed by either the "upstream" or the "downstream" methods as shown in Figure 3-1.

The upstream method, which was extensively used in the past, has been largely replaced by the downstream method. The upstream method has the disadvantage that the upstream section of the dam is founded on slimes which may be unstable resulting in a potential for failure of the dam. The downstream method enables the use of tailings as a construction material while eliminating the disadvantage of the upstream method.

The major disadvantage of the downstream method of construction is the large volume of sands required to raise the dam. In the early stages of operation, or where relatively fine grinding of the ore is employed, it may not be possible to produce sufficient volume of sands to maintain the crest of the tailings dam above the rising pond level, particularly as the quantity of material required for a unit increase in height increases as the structure progresses. Most of the downstream construction techniques use some

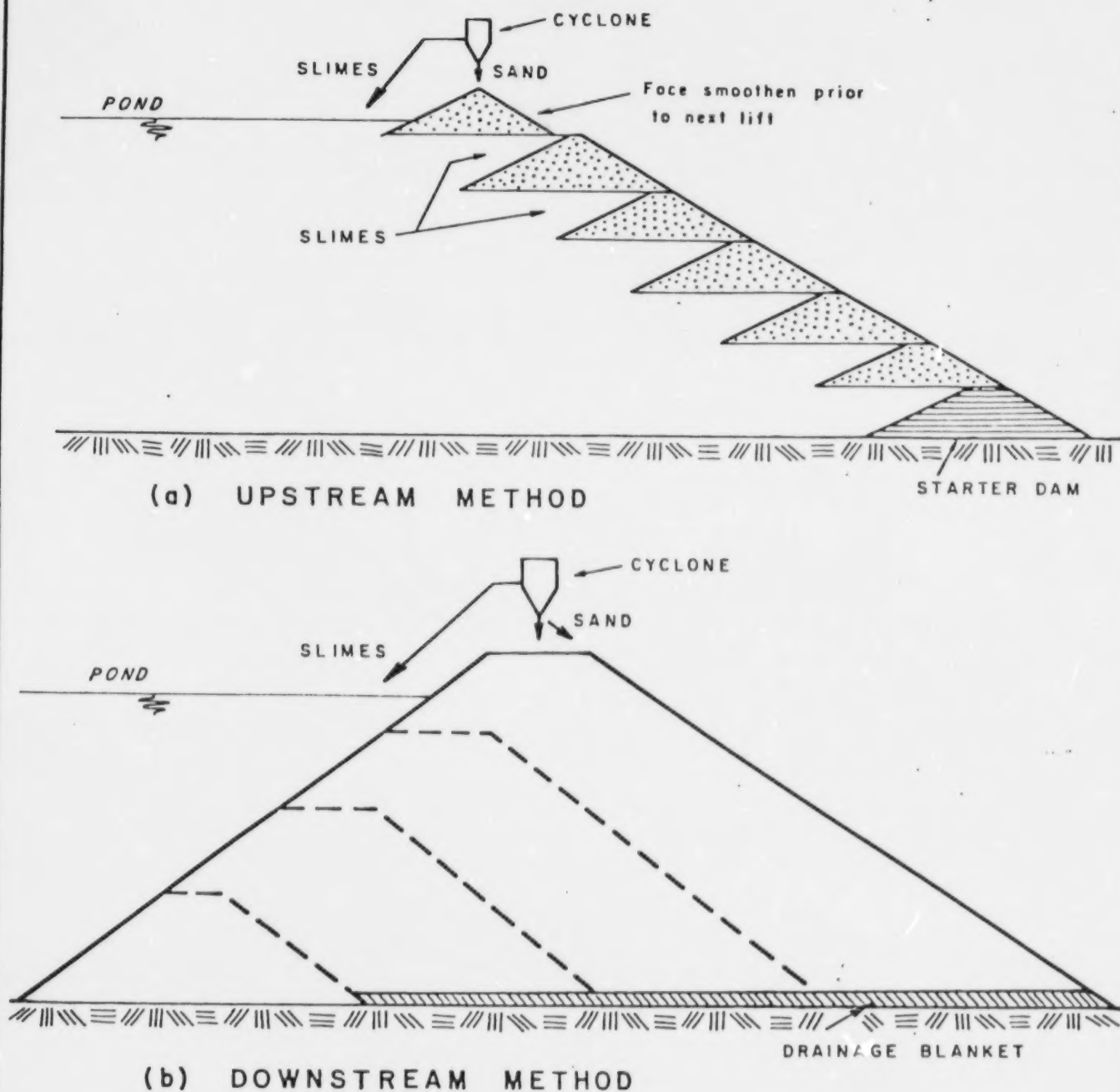


FIGURE 3-1

SECTIONS OF DAMS USING TAILINGS
AS CONSTRUCTION MATERIAL

variation of a cyclone to segregate the coarse tailings and divert them to the outer face of the embankment.

A number of mine/mills in Canada use special select methods to contain tailings. At the Kidd Creek mining operation in Timmins, Ontario, mill tailings are thickened and pumped to a central spigotting location inside a 1200 ha tailings disposal area which is enclosed by a gravel dyke. The system is designed to build a mountain of tailings sand in the central area and thus keep the height of the perimeter dyke to a minimum.

3.4 TRANSPORTATION OF TAILINGS

In the past, the close location and lower elevation of the tailings disposal area relative to mills enabled a number of mine/mill operations to dispose of their tailings by gravity discharge using launders or pipelines. Today, the changes in siting criteria of tailings impoundments have meant that a majority of mills must pump their tailings to the disposal area.

Until recently, a majority of the Canadian operations used wood stave pipes to transport tailings. The main reasons were the price, availability, wear characteristics and insulating value. With changes in the technology and economic conditions, the majority of recent designs have specified polyethylene pipe except where higher pressure installations dictate the use of other materials. Pre-insulated polyethylene pipes are now available and have been used both in new designs and to replace old wood stave pipes. At Cominco's Sullivan mine, in British Columbia, for example, the old launders on trestles have now been replaced by a system of polyethylene pipes with vertical concrete drop boxes to minimize pipe gradient.

Topography generally dictates the slopes of tailings lines. The variations are large but when choice is possible, the selection falls between 0.5 percent and 1 percent with drop

boxes used to reduce the grade in steep sections. Generally, tailings are pumped at a solids content between 10 and 15 wt% and at pipeline velocities of 1.5 to 2.1 m/s. At INCO's Copper Cliff operation, for example, tailings are pumped in 500 mm diameter, polyethylene pipes at a velocity of 1.8 m/s to minimize pipe wear.

3.5 OPERATION OF TAILINGS DISPOSAL AREAS

The primary purpose of the tailings disposal area is the permanent storage of rejected solids. Proper distribution of tailings into the disposal area is essential to ensure effective use of the available capacity of the area. Normally, the tailings are spigotted or cycloned onto the upstream face of the impoundment dam (Figure 3-1) in order to provide material for periodically increasing the height of the dam. The height is increased by "pushing" (bulldozing) the deposited sands so as to construct the dam.

Spigots consist of a series of pipes which make use of the main tailings pipeline as a header. Discharge of tailings through the spigots results in collection of sands along the upstream edge of the tailings dam. These sands are then used as construction material to raise the elevation of the dam. The slimes separate from the sands during spigotting and flow towards the pool and decant area of the tailings pond.

Supernatant from the majority of tailings pond operations are discharged by decantation. Very few operations use spillways or weirs. The use of permanent decant structures is the most prevalent method of decanting water from tailings ponds followed by floating pumps and siphons. The latter methods are more recent, more flexible and are normally installed in operations with larger than average milling capacities and for tailings dams with high ultimate heights.

Permanent decant towers are normally constructed of concrete but occasionally of steel pipe, coated for corrosion

protection. Their main advantages are low operating costs and flexibility in order to handle spring runoff. The disadvantages are that they are fixed in location, have a high potential for structural failure and should problems due to plugging or shifting occur, remedial measures may be difficult. At Cominco's Sullivan operation in Kimberley, B.C. the operation of the old decant towers and the underlying clay tile piping was discontinued in 1983 in favour of a decant pumping and surface piping system. This change was initiated because of the questionable security of the old decant system and the potential consequences of its failure.

It is very common for the tailings pond to serve as a source of recycle water and as a treatment system for contaminated surface drainage and minewater. In other cases, the tailings pond serves as a collection and flow balancing pond for contaminated waters, treatment being carried out in a separate treatment plant.

The quantity of water to be discharged to the environment by those operations which impound their tailings is primarily determined by their ability to maintain a stable and satisfactory water balance in the processing and impoundment system. The general trend in the milling industry is towards an increasing use of recycle water. This practice can reduce the amount of freshwater required and the amount of effluent to be discharged. Very rarely, however, can this discharge be reduced to zero because of the Canadian climatic conditions and because most processes require at least some influx of freshwater. Tailings impoundments are therefore always operated such that there is a pool of water near the discharge end. This pool may vary in size and volume over the lifetime of the operation. The pool acts as a clarifier and provides the necessary storage for recycle water and effluent discharge.

Although the trend in the mining industry is to use more recycle water, there can be constraints on where the recycle water can be used in a process. Returning reagents or their

breakdown products can have deleterious effects on the metallurgy of the concentrator. Also it is not suitable for use in pump glands or for equipment sealing and cooling. Sometimes, the decant from tailings ponds is aged in secondary ponds to promote passive treatment using light, bacteria, oxygen, natural evaporation and time, to remove, destroy or break down organic and other compounds in the water so as to make it more suitable for recycle.

3.6 RECLAMATION OF TAILINGS DISPOSAL AREAS

361 OBJECTIVES

The general intent of tailings pond reclamation is to return the tailings area after the cessation of mining/milling activities to a semblance of the state of land prior to mining. For the site as a whole, this might include the sealing of shafts, dismantling and removal of all buildings, equipment and foundations and revegetation of all disturbed lands including waste dumps and the tailings disposal areas.

Reclamation of a mine site is generally commenced following completion of mining activities. Prior to the 1960's many mining sites were abandoned without significant reclamation attempts. Current practice in mine planning is to include a conceptual reclamation plan for the tailings disposal area as part of the regulatory approval process. This plan normally includes a commitment to reclaim the site following completion of the mining activities.

362 RECLAMATION PROCEDURES

Revegetation is the primary reclamation method for tailings disposal areas. Revegetation, which is considered in Section 5, stabilizes the surface of the area, improves the aesthetics of the area, and reduces, to some degree, the access of oxygen and water to the tailings. Other methods of reclamation such as the use of surface binders have received

little application. Other methods that have been considered such as the use of bactericides, removal of ferrous sulphides to minimize acid generation potential, and application of surface binders, are generally categorized as aids to reclamation.

Possibly the most effective method of reclamation and tailings stabilization has been recorded for those situations for which sulphide tailings were discharged into a body of water. Observations by Cominco (Appendix B-8) at the Bluebell Mine operation in British Columbia indicate that acid generating sulphide tailings discharged into Kootenay Lake show no evidence of oxidation. It is estimated that approximately 1.5 million tons of tailings were discharged into the lake during the period from 1952 to mine closure in 1971. Recent metallurgical test work on zinc rich samples of the tailings indicate that oxidation has not occurred. This behaviour is very consistent with the fact that flooding of sulphide tailings provides a very effective barrier to the transport rate of oxygen into the sulphides (Ohio State, 1971). Similar observations have been recorded at Cominco's former Benson Lake operation on Vancouver Island (Appendix D-21), and at the HBMS Anderson Lake, and Mandy Mine operations in Manitoba (Appendix B-16).

Cominco operated a mine at Benson Lake from 1963 to its closure in 1973. Approximately 2.1 million tons of tailings containing pyrrhotite (4%) and pyrite (0.5%) were discharged into the lake. Investigations indicate that no significant degree of oxidation has occurred in those tailings discharged into Benson Lake. Conversely, other tailings, which were deposited on the surface near the minesite, show evidence of sulphide oxidation and "extreme acidity" (Appendix B-9).

The Anderson Lake operation of Hudson Bay Mining (Appendix B-16) employs underwater disposal of sulphide tailings. Tailings have been discharged into the 360 ha Anderson Lake since 1979. The lake contains approximately 1.6 million tons of tailings. The HBMS operation at Anderson Lake is based on observations of the characteristics of sulphide tailings

which were deposited underwater between 1917 to 1944 at their Mandy Mine operations in Manitoba (Appendix B-16). It is known that at the time of deposition the tailings contained pyrite and had a sulphur content of 15 to 17 percent. The tailings deposition area was investigated in 1975-76, approximately 32 years following deposition of tailings into Mandy Lake. The investigations indicate that oxidation of the tailings has been decreased by underwater disposal. The investigation also determined that vegetation has been established on the flooded tailings resulting in a thin layer (maximum of 2.5 cm) of organic material over the tailings deposit. In addition, there appears to be no effect of the tailings on water quality of the lake. Unfortunately, no data are available to indicate the effect of the tailings on the lake from the time of initial disposal to the present.

In general, regulatory agencies do not favour the underwater disposal of tailings. However, this method certainly warrants further study due to its apparent effectiveness as an inhibitor of sulphide tailings oxidation. While of limited benefit as a reclamation method for many existing tailings disposal areas, this method may be of real benefit to future mine developments.

PART FOUR
ACID FORMATION AND TREATMENT TECHNOLOGY

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4.0 ACID FORMATION AND TREATMENT TECHNOLOGY

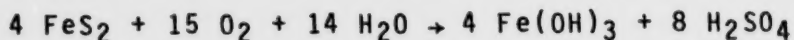
This section of the report considers the mechanisms of acid formation within sulphide tailings, at source abatement of acid formation, and technology for the treatment of acidic drainages.

4.1 ACID FORMATION

The processes, which result in the generation of acidic, metals containing seepages and drainages from sulphide tailings, have received considerable study. Information concerning the generation of acidity has been developed primarily through laboratory scale investigations. Less information is available in the literature concerning field scale investigations. At this time, it can be concluded that the overall chemical reactions that generate acidity are well known. In addition, the influence of various microorganisms in enhancing the generation of acidity has been defined. The reaction pathways and fundamental mechanisms of both the chemical and biochemical processes are less well defined and are a subject of continuing research.

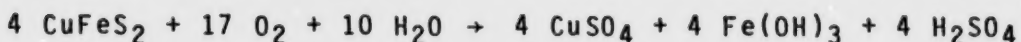
4.1.1 OVERALL REACTIONS

Various metal sulphides generate acid when oxidized. The rate of oxidation is enhanced by various microorganisms capable of survival in acidic conditions. Complete oxidation of pyrite (FeS_2) and pyrrhotite ($\text{Fe}_{1-0.8}\text{S}$), those iron sulphides commonly present in "massive" quantities in sulphide tailings, results in the generation of sulphuric acid in accordance with the following overall reactions:

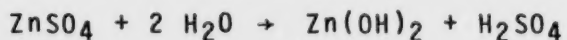
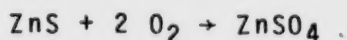


Similarly, the oxidation of other basemetal iron sulphides,

such as chalcopyrite (CuFeS_2) can also result in the generation of acid:



Oxidation of the more simple non-ferrous basemetal sulphides also results in the generation of (weakly) acidic solutions due to hydrolysis of the metal ion:

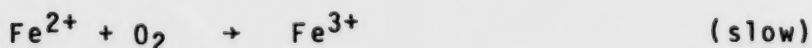
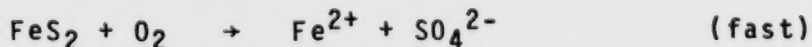


Oxidation of the iron sulphides such as pyrite and pyrrhotite have been studied in the most detail due to their relatively high abundance in coal and in base metal ores and tailings. The other metal-ferrous sulphides tend to be present in relatively small quantities and are not regarded as the prime sources of acid generation. However, the leaching of the metallic elements from these sulphides due to the acidic conditions generated by oxidation of pyrite and pyrrhotite is a major concern.

412 OVERVIEW OF OXIDATION PATHWAYS

Three pathways have been identified for the oxidation of pyrite (Lowson, 1982). Oxidation of pyrite and other ferrous sulphides can occur by chemical, electrochemical, and biochemical oxidation.

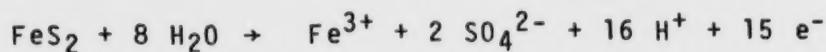
Chemical oxidation occurs by direct contact of oxygen and moisture with the sulphides. Chemical reactions result in oxidation of both the ferrous iron and sulphur, to ferric iron and sulphate, in accordance with the following sequence of reactions (unbalanced):



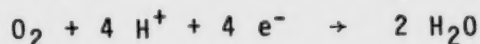
The ferric iron generated by the oxidation of ferrous iron can itself act as an oxidant, resulting in oxidation of pyrite:



Electrochemical oxidation occurs by an electron transfer process. The iron sulphide reacts with water at an anodic site in accordance with the following half cell reaction:



The electrons are transferred to the cathodic site by an external circuit where oxygen is reduced to water via the following half cell reaction:



Biochemical oxidation (Trudinger, 1967) occurs by means of bacteria which obtain energy for their survival by oxidation of inorganic compounds. The thiobacillus bacteria, particularly Thiobacilli ferrooxidans and Thiobacilli thiooxidans are capable of oxidizing pyrite and other sulphides while surviving in the resultant strongly acidic environments. These aerobic bacteria are capable of survival and growth in simple salt media containing oxidizable inorganic compounds, with carbon dioxide as the source of carbon for cell development. The bacteria are capable of oxidizing both the ferrous and reduced sulphur constituents present in sulphide tailings.

Excellent reviews of the various oxidative pathways and fundamental mechanisms have been prepared by Lowson (1982) (chemical and electrochemical) and Trudinger (1967) (biochemical).

413 ACID GENERATION AND SULPHIDE TAILINGS

The primary features of acid formation within sulphide tailings are illustrated by the observations of Boorman and Watson (1974) who studied abandoned tailings at Heath Steele Mines in northeastern New Brunswick. The physical and chemical characteristics of the tailings area were determined by sampling of solids and entrained water at various depths at 9 locations within an approximately 4 ha disposal area. The tailings area had been inactive for a period of approximately 10 years. Massive pyrite (~70%) tailings had been deposited in the area to depths of approximately 10 m (~850,000 m³ of tailings).

The physical and chemical characteristics of the tailings varied with depth, with 3 distinct zones being identified. The uppermost zone, approximately 40 cm in depth, was classified as an oxidation zone; this was underlain by a 5 to 10 cm thick hard pan, which in turn was underlain by an undisturbed reduction zone. The reduction zone contained virtually undisturbed (i.e. unoxidized) tailings.

The uppermost oxidation zone contained highly oxidized material and showed extensive leaching of the metal sulphides such as pyrrhotite, sphalerite and chalcopyrite. Galena (PbS) had been largely converted to lead sulphate (PbSO₄). The oxidation zone also contained an "abundance" of bacteria and relatively high concentrations of oxygen.

The hard pan, so designated because of its crust like characteristics, consisted of tailings which had been cemented together by iron oxide precipitates and gypsum. Copper cementation had occurred onto the pyrrhotite and to a lesser extent onto other metal sulphides.

Boorman and Watson interpreted the chemical characteristics of the tailings as a function of the availability of oxygen at various depths through the tailings. Thus, the uppermost oxidation zone, characterized by the ready availability of oxygen, allowed for continuous oxidation of pyrite and

pyrrhotite resulting in a thriving population of bacteria and highly acidic conditions. As oxygen becomes limited due to increasing depth, the oxidation rate decreases, the pH increases, and iron hydroxides precipitate onto the tailings. The observation that the reduction zone, containing virtually undisturbed tailings, existed at a depth of only 50 cm (approximate) below the surface indicates the effectiveness of limiting oxygen as a means of minimizing oxidation and acid generation.

Observations by Cominco at the Sullivan Mine tailings disposal areas (Appendix D20) are consistent with those of Boorman and Watson. Tailings at a depth of more than 70 cm below the surface showed little evidence of oxidation and hard pans of varying thicknesses were observed at variable depths below the surface.

Further consideration of the physical and chemical processes that occur within field scale tailings deposits, particularly as they age, may provide impetus to the development of methods which inhibit the generation of acid. The hard pan for example may or possibly could play an important role in inhibiting the access of oxygen into the tailings and in physically stabilizing the surface of the deposit. Surveys of other abandoned tailings deposits would provide further information in this regard.

As previously noted, the fundamental acid generation processes have received very extensive study, theoretically (Ohio State, 1971), and by bench scale experiments. During the past 15 years considerable advances have been made in the understanding of the characteristics and role of the microorganisms which enhance the generation of acid. At this time, these bacteria are regarded as the major cause of acid generation within sulphide tailings. Although it has been well established that these microorganisms catalyse the rates of oxidation, the fundamental mechanisms by which this occurs are only partly understood. However, it is reasonable to suggest that sufficient knowledge is available to enable interpretation of observations of the processes that occur

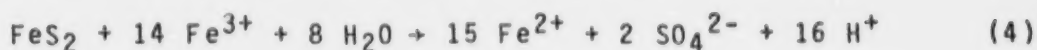
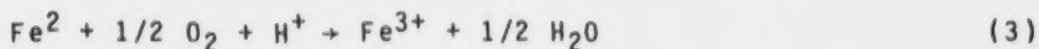
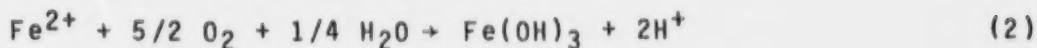
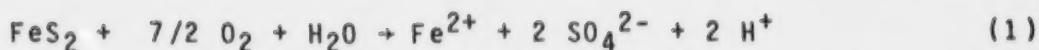
within tailings deposits. Further knowledge of the fundamental mechanisms of biochemical oxidation could of course lead to the development of inhibitory methods based on "blocking" of reaction pathways or establishment of conditions that prevent the survival of these microorganisms.

Cominco has carried out a very complete investigation of the microbiological and chemical characteristics of sulphate tailings in the near surface environment at the Sullivan Mine (Appendix D20). These investigations were carried out in connection with development of revegetation procedures. The data obtained during this investigation are, in general, very consistent with mechanisms of acid generation as reported in the general literature.

Cominco identified a succession of thiobacilli in the tailings from T. thioparus to T. thiooxidans and T. ferrooxidans as the pH decreased. T. thioparus (growth range pH 7.8 to 4.5) predominated at higher pH conditions whereas T. thiooxidans and T. ferrooxidans, as would be expected, predominated as pH decreased. Observations of the mineralogical and chemical properties of the tailings indicated that both ferrous iron and sulphur, present as pyrrhotite, are oxidized. In addition to sulphate, at least traces of other partially oxidized sulphur species (elemental sulphur, polysulphides, thiocyanates, thiosulphate and polythionates) were detected in the oxidized tailings. Sulphate was present primarily as gypsum in the slightly acidic areas and as jarosites in the more highly acidic areas of the tailings.

The observations reported above are very consistent with the mechanisms of acid generation as defined in recent years by Kleinmann et al (1982, 1981, 1979) and others (Kazimiera et al, 1981; Vuovinen et al, 1983).

Kleinmann et al (1981) have defined three phases of pyrite oxidation that lead to the generation of acid. The major chemical reactions responsible for the generation of acid are:



The extent to which any of these reactions occurs depends primarily on the activity of Thiobacillus ferrooxidans, and the pH and redox potential of the tailings environment. The redox potential provides a measure of the extent to which oxidation or reduction can occur within a particular environment.

The first stage of acid formation occurs upon exposure of pyrite to air and moisture. Chemical and biochemical oxidation of the pyrite would occur in accordance with reactions 1 and 2. Ferric iron, generated due to the oxidation of ferrous iron, would tend to hydrolyse and precipitate as ferric hydroxide at the higher pH's characteristic of this initial stage. Reaction 1, the oxidation of pyrite by oxygen, is relatively slow by either of the chemical or biochemical pathways. Thus, if infiltration of water into the tailings is "rapid", the build-up of acid within the reaction zone may be limited. Under this condition the pH within the tailings would remain close to that pH which was characteristic of the tailings prior to exposure of the sulphides to air and moisture. A similar condition would occur if the alkalinity of the gangue materials and/or infiltrating water is sufficient to neutralize the acid as it is slowly generated.

The second stage of acid formation occurs if field conditions allow stage 1 to continue undisturbed, thereby causing a gradual decrease in the pH of the reaction zone. Lack of infiltration of water into the tailings and/or lack of alkalinity in the gangue materials would favour a gradual decrease in the pH of the reaction zone. Under this

condition, the pH would decrease, thereby dramatically improving the environment for the survival and growth of the iron and reduced sulphur oxidizing bacteria, particularly Thiobacillus ferrooxidans. The increased activity of these bacteria would cause an increased rate of acid formation and a continued decrease in the pH of the reaction zone. As the pH decreased, the rate of oxidation of ferrous iron by chemical oxidation would decrease but the rate of biochemical oxidation would increase. As the pH of the reaction zone decreased towards approximately 4.5 to 3, ferric iron produced by biochemical oxidation would remain in solution thereby initiating the third stage of acid formation, oxidation of pyrite by ferric iron (reaction 4).

The third stage of acid formation would occur as a result of there being sufficient ferric iron in solution to act as an oxidant of pyrite (reaction 4). The reduced ferrous iron produced during this reaction would be biochemically reoxidized to ferric iron in accordance with reaction 3. This reaction is regarded as rate controlling during the third stage of acid formation. During the third stage, acid can be very rapidly generated resulting in a further decrease in the pH of the reaction zone.

The extent to which any of the stages described above occurs within a sulphide tailings deposit, exposed to air and moisture, is a complex function of many factors. In some cases the characteristics of the tailings (e.g. alkaline gangue materials) will prevent or limit the extent to which acid is generated (Bruynesteyn and Hackl, 1982). In many other cases, however, oxidation of sulphides can be expected to proceed to the third stage despite hydrologic conditions that result in periodic "wash-out" of accumulated acid in the reaction zone. This can be attributed to the rapid rate at which Thiobacillus ferrooxidans and other organisms can establish and multiply in tailings despite periodic conditions adverse to their growth, such as high pH.

4.2 ABATEMENT OF ACID FORMATION

The formation of acid within sulphide tailings is a complex function of many variables ranging from the minerology of the deposit to the extent to which organic substances are released by bacteria not directly involved in the oxidation processes (Wakao, 1983; Groudev, 1983). Known factors which influence acid formation include those such as:

- morphology of the sulphide minerals
- particle size of the minerals
- salt and nutrient content
- temperature
- pH
- oxidation - reduction potential
- humidity within the reaction zone
- rate of transport of oxygen to the reaction zone
- rate at which reaction products are transported away from the reaction zone
- catalytic materials (bacterial and other).

Development of methods to abate acid formation do not readily follow from a knowledge of the factors which cause or enhance oxidation of sulphides. The inherent nature of tailings deposits (large volumes and surface areas) enhances those conditions which favour acid formation. Thus, it has been difficult to conceive practical abatement methods despite knowledge of the key factors involved in acid generation.

Abatement of acid formation necessitates that entry of reactants (air and moisture) into the tailings be prevented or that measures be implemented which inhibit or prevent the oxidation reactions. Both types of controls are currently used or are being considered for the abatement of acid generation.

Air (oxygen) and moisture are essential reactants for the oxidation of sulphide tailings. Elimination of either or both of these reactants would prevent the generation of acid.

Of these two essential reactants, complete elimination of water is regarded as impractical due to the very small quantity of water required for the oxidation reactions. For example, to generate an acidity of 5000 mg/L (as CaCO_3) by oxidation of pyrite, approximately 10 L of air are required, but only 1.6 ml of water enters the reaction. Water is diverted away from tailings areas as a means of minimizing the transport of contaminants from the oxidation area into surrounding water courses, rather than as a means of inhibiting the oxidation reactions.

Observations of the processes occurring within tailings deposits, that are located on the surface or under water, demonstrate the effects on pyrite oxidation of eliminating oxygen as a reactant. The observation that oxidation of tailings, located on the surface, occurs only within the uppermost layer of tailings (Section 4.2) is directly attributable to lack of oxygen at the lower depths. Similarly, observations of tailings that have been disposed of under flooded conditions indicate that essentially no oxidation has occurred (Section 362). This can be attributed to the limited concentration of oxygen in water (equivalent to approximately 20 mg/L of acidity as CaCO_3) and the very low transport rate of oxygen through a layer of water to the reaction zone (Ohio State, 1971).

There has possibly been too little consideration into means of eliminating or minimizing the access of air into sulphide tailings. Elimination of air as a reactant could prove to be the most effective and economical method for the long term management of sulphide tailings. There is no doubt that this method warrants much more detailed consideration, particularly with respect to site selection and design of any future tailings disposal areas.

Elimination of oxygen as a reactant for existing on-surface tailings disposal areas, as a means of long-term stabilization, may not be practical in many cases due to layouts of the existing disposal area. Present regulatory

requirements and technology centre on revegetation as a means of long-term management of tailings. While there is no doubt that vegetation inhibits the access of oxygen to the buried sulphides, there is insufficient evidence that formation of acid is adequately inhibited in all cases. Most importantly, the formation of acid during reclamation is the primary factor responsible for the difficulties associated with the revegetation of sulphide tailings (Section 5). Thus, other methods, capable of preventing the access of oxygen would eliminate formation of acid, thus facilitating revegetation.

Various inhibitors have been suggested as additives to sulphide tailings in order to prevent acid formation. The use of anionic surfactants, and in particular sodium lauryl sulphate (SLS) has been investigated by the U.S. Bureau of Mines as a bactericide (Kleinmann et al, 1982; 1981). This and other anionic surfactants are bactericidal towards Thiobacillus ferrooxidans and have been shown to reduce acid formation following their application. Kleinmann and co-workers have developed a rubber type matrix (pellets) which allows the substance to be released at a slow rate, thereby increasing the duration of effectiveness. These and other such substances may be useful as inhibitors while revegetation or other more long term stabilization methods are applied to the tailings.

Other chemicals, such as phosphates, and silicates (Watkin and Watkin, 1983), have also been tried as inhibitors. Phosphates have been shown to reduce the rate of acid generation. This is attributed to the precipitation of iron phosphates which remove iron as a potential oxidant of pyrite. Other agents, such as silicates and iron hydroxide precipitates, may act as inhibitors by coating the sulphide particles thereby limiting the access of air. At present, these reagents have been proposed primarily as temporary inhibitors of acid formation to be used as an aid to revegetation efforts.

4.3 TREATMENT TECHNOLOGY

The long term management of sulphide tailings may necessitate, at least in some cases, the treatment of drainage discharged from the tailings area. The drainage could include surface runoff as well as seepages from within the tailings deposit. Treatment could be required to neutralize free acidity and to remove dissolved metals prior to discharge of the treated effluent into the environment. This section of the report considers present practices for the treatment of acidic, metal bearing drainages, particularly as related to the long term management of tailings disposal areas.

The treatment of acidic, metal bearing drainages, generated as a result of mining operations, is very widely practiced in Canada and elsewhere. In Canada, considerable research and other efforts were undertaken during the late 60's and 1970's to improve technology for the treatment of acidic drainages. These efforts led to the report of the Mining Regulations Task Force, titled "Mine and Mill Wastewater Treatment" (Environment Canada, 1975) and the "Metal Mining Liquid Effluent Regulations and Guidelines" in 1977 (Environment Canada, 1977). Most recently, the United States Environmental Protection Agency has published a "Design Manual - Neutralization of Acid Mine Drainage" (EPA, 1983). The manual considers the various unit operations associated with the neutralization and removal of metals from acidic, coal mine drainages.

431 QUANTITY AND QUALITY OF DRAINAGE

The formation of acidic drainages may continue following the reclamation and abandonment of sulphide tailings disposal areas. The quantity of surface runoff and seepages from the tailings disposal area(s) will depend on the local hydrological characteristics, as well as the effects undertaken during the reclamation phase to minimize the

extent to which precipitation and groundwaters come into contact with the tailings disposal area.

Table 4-1 provides an indication of the quality of drainages resulting from the oxidation of sulphides in various regions of Canada. In general, the drainages contain free acidity, iron, and other metals dissolved from the tailings and/or orebody as a result of oxidation and acid leaching processes. Although the quality of the drainage may vary from one tailings deposit to another, the types of constituents are similar for all drainages, that is free acidity, iron and base metal cations, and sulphate as the predominant anion.

432 TREATMENT TECHNOLOGY

.1 Objectives of Treatment

Acidic, metals bearing drainages must be treated prior to discharge into the environment in order to meet federal and/or provincial regulatory requirements. The short and long-term effects, particularly to aquatic habitats, due to the discharge of untreated drainages into the environment have been well established (e.g. MECo, 1972). Thus, treatment is normally carried out to:

- remove suspended solids
- neutralize free acidity
- remove iron and other metals, particularly arsenic, copper, lead, nickel and zinc.

Water quality limits specified in the National Liquid Effluent Regulations are summarized in Table 4-2. In general, these are regarded as minimum objectives by the federal and provincial regulatory agencies. More stringent requirements can be imposed, in particular situations, if this is regarded as necessary to protect the environment.

TABLE 4-1
Acid Drainages Composition

Source ^a	Suspended Solids (mg/L)	pH	Total Acidity (mg/L as CaCO ₃)	Metals (mg/L)							SO ₄ (mg/L)
				As	Al	Cu	Fe	Mn	Pb	Zn	
Heath Steele Mines Ltd. (NE New Brunswick) (SD + MW)	5-90	2.8-3.3	500-1500	-	-	1-52	24-230	-	0.1-5.0	18-175	810-1790
Brunswick No. 12 (NE New Brunswick) (MW)	-	2.6-3.0	-	-	-	5-12	500-1200	-	3-7	1700	1200
CECO (Ontario) (MW + TP Seep.)	-	3.9	-	-	-	3.4	460	-	-	120	-
Cominco, Kimberley (B.C.) (MD)	200-900	2.5-4.0	-	-	35-150	-	200-1000	20-75	2-5	30-200	-
Cominco, Kimberley (B.C.) (TP)	25-100	3.0-5.0	-	-	-	-	300-2500	5-30	2-8	10-50	-

^a SD - Surface Drainage
MW - Minewater
TP Seep - Tailings Pond Seepage
TP - Tailings pond water

Table 4-2

Metal Mining Liquid Effluent Regulations and
Guidelines - Effluent Water Quality Requirements

	Maximum Monthly Arithmetic Mean	Maximum Concentration - Grab Sample
Suspended Solids (mg/L)	25	50
Arsenic (mg/L)	0.5	1.0
Copper (mg/L)	0.3	0.6
Lead (mg/L)	0.2	0.4
Nickel (mg/L)	0.5	1.0
Zinc (mg/L)	0.5	1.0

Minimum pH in grab sample - 5.0

Source: Environment Canada, 1977

.2 Technology

The neutralization of acidic drainages resulting from sulphide mining operations has been carried out for many years. During the late 1960's and early 70's, emphasis was placed on obtaining a more complete understanding of the treatment process. The need for a more complete understanding resulted primarily from the recognition of the environmental effects of inadequately treated drainages on aquatic resources. This resulted in both bench and pilot scale investigations by mining companies as well as government agencies, leading to the guidelines, regulations and task force report previously referred to in Section 441.

At present, treatment systems of various types and capacities are in operation in Canada for the treatment of acidic mine drainages. Present practices almost invariably include the following treatment operations:

1. Collection of the drainage(s)
2. Neutralization with aeration to remove free acidity, oxidize ferrous to ferric iron, and precipitate base metals as metal hydroxides
3. Solids-liquid separation to produce a metal hydroxide sludge and clarified overflow suitable for discharge into the environment, and
4. Ultimate disposal of the metal hydroxide sludge.

In some cases, particularly for gold and silver mining operations, treatment for the removal of arsenic, and cyanide is also required. Treatment for arsenic removal is almost invariably based on the iron addition method, whereby arsenic is co-precipitated with ferrous or ferric hydroxide, or otherwise adsorbed onto the iron hydroxide floc. Various methods have been implemented for the oxidation of cyanides to produce less toxic or non-toxic effluents (Ingles and Scott, 1981).

At some minesites, the acidic drainages are simply treated by discharge into the alkaline tailings pond. This is the case at Heath Steele Mines in northeastern New Brunswick where sufficient excess alkalinity is added to the mill tailings to maintain the tailings pond at pH 9-10, despite the addition of mine and surface drainages directly into the tailings pond. In other cases, such as at Cominco's Kimberley operation, the acidic drainages from the tailings disposal area as well as from the underground workings and other areas of the operation are collected, combined, and then treated in a "mechanical" treatment plant.

Treatment methods based on the following processes can be considered as "best practicable technology":

- neutralization of the drainage with hydrated lime (Ca(OH)_2)
- oxidation of ferrous iron under alkaline conditions by aeration
- precipitation of ferric iron and base metals at pH of 9 to 10, and
- clarification following coagulant/flocculant addition.

This technology is used at both active and abandoned mining operations throughout the sulphide mining region of Canada. Descriptions of a number of treatment systems currently in operation in various areas of Canada are given in Appendix C. The application of this technology is well demonstrated by the treatment system in operation at Cominco's Kimberley, B.C. operations (Appendix C-17).

Cominco's treatment system at its Kimberley, B.C. base metal mining operations has been planned on the basis that the facilities may have to be kept in operation for an extended period following the completion of mining activity (Kuit, 1980). Major components of the system include use of the tailings disposal areas for storage and balancing of the various wastewaters, use of the high density sludge lime neutralization process, and disposal of the sludge in a designated landfill area.

Minewater, concentrator effluent, and surface runoffs are collected in the tailings disposal areas which provide storm runoff balancing capacity as well as equalization of the various wastewater compositions entering the storage area. The acidic and metals bearing water is pumped into an 1080 m³/h capacity treatment plant. The treatment system (Kuit, 1980) consists of reagent preparation systems (limeslaker and flocculant), neutralization/aeration reactor, flocculation tank, conventional clarifier, and a reactor for the mixing of recycled clarifier sludge with lime slurry prior to addition to the wastewater under rapid mix conditions. The recycling of clarifier underflow sludge, and its contact with lime slurry prior to addition to the wastewater, results in a high density hydroxide sludge (20 to 30 wt%) which is disposed of by the landfill method.

The oxidation of ferrous iron by aeration under alkaline conditions results in stable and highly insoluble ferric hydroxide. Complete oxidation of the ferrous iron has been shown to improve the settling characteristics of the precipitated metal hydroxides and results in lower concentrations of base metals due possibly to coprecipitation and adsorption phenomena associated with the formation of ferric hydroxide. Oxidation of ferrous iron is also necessary to ensure the stability of the metal hydroxide sludge. Disposal of ferrous rich sludge can result in generation of acidic conditions within the sludge due to the oxidation of the ferrous iron under alkaline conditions.

Approximately 18 t/d of metal hydroxide sludge are disposed of by the landfill method. Cominco has developed a rather unique method for the disposal of sludge which could have application at other minesites. The sludge disposal area is underlain by permeable deposits of sand and gravel materials. Drainage of water from the sludge through the underlying material combined with the ingress of atmospheric carbon dioxide into the sludge results in the formation of a calcium carbonate type matrix which enhances the long term stability of the sludge. The stability of the sludge has been

confirmed by laboratory testing. Routine monitoring of groundwaters around the disposal area has also demonstrated that the sludge is stable with respect to the dissolution of metals. The effectiveness of the treatment system for the removal of metals is shown by the effluent water quality data given in Table 4-3. It should be noted that the annual operating cost of the treatment system is approximately \$1 million per year. This cost, which is regarded by Cominco as a significant burden, would not be expected to decrease significantly if the treatment system were kept in operation following shutdown of the mining operation. This is obviously a key concern with respect to the eventual closure of the minesite.

Technology for the treatment of acidic, metal bearing drainages is well developed with respect to application to the long term management of sulphide tailings. The mining industry has considerable experience related to the collection of contaminated drainages and treatment of these to meet provincial and federal effluent water quality requirements. Key concerns are related to the annual operating costs of treatment, beyond the lifetime of the mining operation, and the requirement to dispose of sludge.

Major contributors to the operating costs of treatment are the costs of reagents (lime and coagulant/flocculants), and labour. In general, present technology enables the minimization of labour requirements. The costs of reagents are primarily a function of the total acidity and quantity of drainage that must be treated. Hence, minimization of the cost of reagents depends primarily on the degree of success that can be achieved in reducing the generation of acidic drainages.

The need to dispose of metal containing sludges is of major concern. At present, disposal of sludges in ponds and as landfill are regarded as the most practicable and economic methods for ultimate disposal. However, the sludges themselves pose a potential source of contaminated drainages

TABLE 4-3
Cominco Kimberley Operations -
Treated Effluent Water Quality

	Effluent Water Quality
Suspended Solids (mg/L)	<15
pH	9.5
Copper (mg/L)	<0.05
Iron (mg/L)	<1.0
Lead (mg/L)	<0.1
Zinc (mg/L)	<0.2

Source: Kuit, 1980

and hence continued research is warranted, particularly as regards to sludge stability and sludge volume.

PART FIVE
REVEGETATION

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5.0 REVEGETATION

Revegetation (Appendix D) is one aspect of minesite reclamation; however in some areas, such as British Columbia, the two terms are synonymous. Revegetation is the process of establishing vegetative cover on mineral wastes or other disturbed areas in order to:

- stabilize materials subject to wind and water erosion
- maximize evapotranspiration to minimize the quantity of infiltration and runoff
- reduce oxidation and potential acid mine drainage
- improve the aesthetic value of the site.

5.1 CHEMICAL AND PHYSICAL PROPERTIES

The chemical properties of sulphide mine tailings generally provide a poor environment for plant colonization. Although the pH of sulphide tailings may be near neutral at the time of deposition, it may decrease to extremely low levels (pH_v2) as a result of the oxidation of sulphides and the generation of sulfuric acid. An examination of Sullivan tailings for example (Appendix D20), revealed pH of the siliceous unoxidized tailing to be approximately 6.2 (5.6-6.9) and unoxidized iron tailing to be approximately 6.0 (5.8-6.1). Oxidation of these tailings resulted in pH values of 2.6 (2.4-2.8) and 2.2 (2.0-2.5) respectively. Levels of extractable metals may vary widely between sample sites and at various depths within the same site. Nutrients important for plant growth (such as nitrogen, phosphorous and potassium) may be lacking. Tailings may contain variable levels of water soluble salts as a result of the oxidation of sulphides and subsequent formation and accumulation of soluble reaction products. The concentrations of salts can be detrimental to the establishment and survival of vegetation.

Initially, sulphide tailings are composed of sand and silt size particles whose bulk density may inhibit root

penetration. As the tailings age, the oxidation processes may increase the clay size fraction of particles thereby improving water retention and the cation exchange capacity. The oxidation may also reduce the bulk density of the near surface zone of tailings, allowing for better root penetration.

511 LIMITS TO PLANT GROWTH

The surface of sulphide tailings provides a harsh environment for the establishment of vegetation. High summer temperatures, due to the absence of shade, and low soil moisture, due to the lack of organic matter, are two major obstacles to plant growth. The surface texture of tailings may not provide an appropriate rooting medium. Loose texture tailings may be subject to wind or water erosion and more compact tailings may have a bulk density of sufficient magnitude to eliminate root penetration. In certain cases, an impervious hard pan surface layer forms that effectively eliminates the establishment of vegetation. Emissions of dust from unvegetated areas can destroy vegetation due to a "sand blasting" effect.

The chemical characteristics of acid generating tailings are also very detrimental to growth of vegetation. Low pH, high salt content, and lack of essential nutrients are all detrimental to revegetation.

512 REVEGETATION EXPERIENCE

A summary of revegetation experiences at a number of sulphide tailings sites is given in Table 5-1. As is evident from Table 5-1, revegetation attempts have met with varying degrees of success. However, it is apparent that successful site specific techniques have been developed during the last few years after many years of research. Successful revegetation normally entails at least multiple applications of neutralization reagents (lime and/or limestone) and

fertilizer. Often, the quantity of neutralization reagent and fertilizers that must be applied at field-scale is much greater than had been expected based on growth room studies and plot trials. The covering of tailings with a suitable plant growth medium, such as topsoil, or other overburden, is another approach to revegetation. A drawback to this treatment, in some cases, is that direct contact between the overburden and tailings eventually leads to contamination of the overburden with acid and salts through capillary action. However, a layer of coarse material, such as crushed gravel, placed between the overburden has been used as a barrier to the migration of acid and salts into the growth medium. This is very expensive but may result in the most successful revegetation. The properties of tailings may vary widely throughout the area and depth of the site. Thus, it is often not possible to apply the results of limited growth room studies and plot trials to the whole area to be revegetated.

Revegetation experiences to date have shown that a common revegetation method, which would be applicable to all sulphide tailings, is an unlikely prospect. Each sulphide deposit must be assessed on an individual basis. However, there is certainly sufficient experience within Canada to enable the development of revegetation plans based on site specific considerations.

TABLE 5-1
Revegetation Experiences

Mine Tailing	Year/Reference	Revegetation Treatment	Results
Sullivan Mines siliceous tailing (British Columbia) Small experimental plots	1978/ D-20	Liming siliceous tailing with 100, 200, 300, and 400 t CaCO ₃ /ha, followed by fertilizer application and planting with a variety of vegetation.	During first 3 years, satisfactory plant growth at 3 lower lime application rates - 400 t/ha produce overly alkaline conditions. At this time acid conditions were beginning to reappear at site of lowest lime application and plant production had begun to decrease.
1.5 ha	1980/ D-20	Liming siliceous tailing with 60, 90 and 120 t CaCO ₃ /ha followed by fertilizer and planting with a variety of grass species. Follow up fertilizer applications.	Vegetation cover ranged from 45-82 percent.
1 ha	1977/ D-20	Covering oxidized siliceous tailings with overburden (15-120 cm).	After six growing seasons, acidic conditions were beginning to reoccur at soil depths of 15 cm or less. With 30 to 60 cm soil cover, vegetation ranged from 50 to 75% complete. With more than 60 cm soil, vegetative cover exceeded 75%.
<1 ha	1977/ D-20	Liming siliceous tailings at application rates of 103, 206, 308 and 411 mt CaCO ₃ /ha. Areas were fertilized and planted with a variety of acid and salt tolerant grasses and legumes.	Seedling establishment was poor on all sites possibly due to high salts and alkaline conditions at high lime application rates.
<1 ha	1978/ D-20	A 7.5 cm layer of peat moss was incorporated into the tailing surface of smaller subplots.	Again poor seedling establishment resulted but best growth occurred in areas of peat. Two years later, areas limed at lowest rate were returning to the acid state. Tailing limed at approx. 200 t/ha produced the best results, pH was maintained at 7.6 - 7.8 for a number of years. Higher application rates produced alkaline conditions that did not permit plant establishment for a number of years. Salt concentrations were greatest with highest and lowest lime application.
Sullivan Mines oxidized iron tailing (British Columbia) Small experimental plots	1978/ D-20	Small scale field trial involving lime applications to iron tailing at rates equivalent to 90, 180, 270 and 360 t CaCO ₃ per ha, followed by seeding, fertilizer and monitoring.	90 t CaCO ₃ did not maintain pH above 2. Maximum cover and biomass occurred in areas limed at 180 t/ha. Within 5 years limed tailings had returned to strongly acid conditions. Vegetation cover was dead in areas limed at 90 t/ha; severely reduced in areas of 180 t/ha and thriving in areas of 270 t/ha. All conifer trees had died on every site.
<0.25 ha	1978/ D-20	Covering tailing with overburden of glacial till 30, 60, 120 cm depth directly on tailing as well as on 30 to 45 cm float rock on tailing surface	30 cm overburden in direct contact with tailing surface became contaminated with acid and salt. Within 5 years all vegetation on 30 cm overburden directly on tailing and much of vegetation on 60 cm had died. Vegetation on all soils over float rock survived. The deeper the soils, the better the moisture and plant establishment.
Experimental plots	1975/ D-20	Covering iron tailing with gypsum overburden and adding 8, 16 and 24 t limestone per ha, plus fertilizer.	After 8 growing seasons, grass cover was maintained on all treatments. However, continued applications of fertilizer containing N is essential.
Coast Copper Mine (British Columbia) Experimental plots	1975/ D-21	Test plots on coarse textured tailing received limestone at 7, 13 and 20 t/ha and 11, 22, and 33 t/ha on medium textured tailing material. Phosphorus fertilizer was applied at rates equivalent to 55, 110, 220 and 440 kg/ha, nitrogen and potassium applications remained constant at 55 kg/ha for all treatments.	Establishment of vegetation was not successful on any site due to insufficient limestone.
Experimental plots	1976/ D-21	Hydrated lime was added to plots on medium textured tailing to raise lime application rates to equal 54, 81 and 105 t/ha. Additional sites on medium texture tailings were treated with 54, 83 and 110 t/ha lime and limestone.	During first 3 growing seasons vegetation grew best on site with 54 t/ha lime. Application of 83 and 110 t/ha produce too alkaline conditions initially but by third growing season conditions improved.

Continued

TABLE 5-1 (Continued)

Revegetation Experiences

Mine Tailing	Year/Reference	Revegetation Treatment	Results
Coast Copper Mine (British Columbia)	1973/ D-21	Tailing disposal area fertilized and planted lime applications.	Results show variable success. Patchy distribution of vegetation - generally poor results.
Cominco's Con Mine growth room studies (NWT)	1973/ D-22	Fertilizer additions on tailing material	Excellent grass growth on slightly to moderately saline tailings, unsuccessful vegetation establishment. Discontinued fertilizer applications reduced cover.
	1973/ D-22	Addition of peat moss to strongly saline 18 mmhos/cm tailings in amounts equivalent to 0, 22, 44 and 88 t/ha.	Highest rate of application reduced the effects of salinity and improved plant cover.
	1978/ D-22	Leaching with 1 cm of water per cm depth of tailing reduced tailing conductivity from 18 mmhos/cm to 2 mmhos/cm.	Improved plant growth.
Con Mine field experiments	1978/ D-22	Peat moss applied to surface in layers ranging from 0-15 cm tilled into the tailing to a depth of 15 cm. Fertilizer and a variety of grass seed was applied. Peat moss applications were equivalent to 0, 88, 132 and 176 t/ha.	Peat moss additions improved the growth of salt tolerant grass species and increased the survival of less tolerant varieties.
Experimental plots	1978/ D-22	Leaching of salts from tailings with the equivalent of 1.2, 0.6 and 0.3 ha-m of water.	Lowered tailings conductivity from 17 to 2 mmhos/cm.
	1978/ D-22	Selection of native salt tolerant grass species.	Have demonstrated satisfactory survival and growth slightly saline tailings.
Cominco's Bluebell Mine tailing (B.C.) <5 ha	1977/ D-23	Tailing area was first site prepared and contoured to reduce slopes. Fertilizer and seed was applied, tree seedlings were planted (total cost \$35,000).	No results to report.
Cominco's Pinchi Lake mine tailing (B.C.) 32 ha	1971/ D-23	Operating program was based upon laboratory growth room and field research programs. Fertilizer and seed was applied.	Fertilizer improved growth of native plants. Initial results report success.
Noranda's Waite-Amulet tailing dam (Quebec) 40 ha	1969/ D-25	Several attempts to neutralize tailing dam with up to 7 t/ac lime followed fertilizer and seed applications.	Unsuccessful.
	1978/ D-25	Growth room bioassay testing was conducted and another operational scale attempt was made based on the lab results.	This time they were successful in maintaining vegetative cover.
Noranda's Horne Division No. 3 Dam (Quebec) 18 ha	1978/ D-25	Same treatments that finally proved successful at the Waite-Amulet site	Did not produce complete vegetation cover.
Qumont No. 1 Dam (Quebec) 0.1 ha test plots	1971/ D-25	An attempt to neutralize tailings with applications of 50-200 t/ac limestone.	Vegetation cover establishment appeared to be better in cases where 100 or more tons of limestone was used.
Normetal Mine tailings (Quebec) 3 ha test plots	1969/ D-25	An attempt was made to neutralize tailings with 7 t/ac lime, area was fertilized and seeded.	Totally unsuccessful
2 ha test plot	1970/ D-25	Another attempt was made with 10 t/ac lime plus wood chip mulch.	Mulch appeared to help but results were still unsatisfactory.
2 ha	1971/ D-25	Further testing suggested 30 t/ac limestone would greatly improve vegetation growth and survival.	
Small test plots	1971/ D-25	An attempt was made to neutralize the tailings with the addition of asbestos tailing material.	Unsuccessful results.
3 ha	1973/ D-25	An overburden of sand and clay was deposited.	Vegetation was successfully established.

Continued

TABLE 5-1 (Continued)
Revegetation Experiences

Mine Tailing	Year/Reference	Revegetation Treatment	Results
Mattabi Mine tailings (Ontario) <1 ha	1975/ D-25	Small field plots were treated with the equivalent of 209 lb/ac lime plus 209 lb/ac limestone, then fertilized and planted.	Unsuccessful.
<1 ha	1975/ D-25	The treatment was changed to the equivalent of 209 lb/ac lime plus 1394 lb/ac limestone.	Unsuccessful.
<1 ha	1975/ D-25	An additional 1394 lb/ac limestone was applied.	Unsuccessful.
<1 ha	1975/ D-25	An additional 1394 lb/ac limestone was applied.	Limited vegetation.
		All further attempts to revegetate Mattabi tailings failed while attempts to revegetate overburden an area of stockpile (sand, gravel and clay) were successful.	
Noranda Mines Geco Division (Ontario) 4 ha	1970/ D-25	Lime was applied at a rate of 5 t/ac, the tailing was fertilized and planted.	Unsuccessful in providing cover vegetation.
4 ha	1976/ D-25	Then tried revegetating soil overburden deposited on tailing with a 6 in layer of gravel between the two mediums.	A lush vegetative cover was produced.
	1976/ D-25	A series of bioassay tests carried out in the lab determined that most of sampled tailings could be neutralized sufficiently for plant growth with additions of 25 t/ac limestone, one sample suggested 50 t/ac limestone would be required.	
Langmuir Mines (Ontario) 2 ha	D-24	Overburden of borrow material was placed on dams, fertilized and seeded.	Excellent vegetative cover was established.
Inco's Copper Cliff Mine Tailing (Ontario) 600 ha total	D-24	Inco's proven revegetation procedures are based upon neutralizing the surface layer of tailings with lime, followed by fertilizer and seed applications. Maintenance applications of fertilizer are usually required. Crops grown on the tailings may be harvested and used as mulch on dryer sites.	Approximately 600 ha of tailing have been successfully revegetated over the past 30 years.
Falconbridge Nickel Rim Mine Tailing (Ontario) Experimental plots	1970/ D-26	Field tests were designed to determine the amount of CaCO ₃ required to neutralize the tailing for plant survival and to determine if the addition of a straw-asphalt mulch improved plant establishment. All sites were fertilized with a mixture of 10-10 agricultural fertilizer.	Plants on all sites survived the initial 2 month test period. CaCO ₃ applied at 10 t/ac produced the best results. Obvious benefits in terms of plant production resulted from the use of mulch.
Experimental plots	1970/ D-26	Additional field tests were designed using 10 t/ac CaCO ₃ and 1/2 t/ac 10-10-10 fertilizer to determine how vegetation would respond to various soil overburden materials, to determine the effectiveness of other mulch materials as well as identify the most suitable plants for revegetation	A 6 inch layer of black loam soil proved to be superior to other local soils used as overburden. All mulch covers tested showed results superior to no mulch. The most suitable plant species for revegetating Rim Mine tailing proved to be: fall rye, bromegrass, red top, colonial bentgrass, creeping red fescue, sheep fescue, sweet clover, alfalfa and white clover. Additional testing determined that 6-9-6 50% urea formaldehyde fertilizer was a superior long term product.
Hardy Pyrrhotite stockpile (Ontario) 7 ha	D-27	The 17 acre area was covered with a 6 ft sand-gravel overburden. 300 lb/ac of 12-18-12 40% sulphur coated area fertilizer was applied.	After 5 years the vegetation cover still existed and native weed and tree species were beginning to establish on the site.
East Mine tailing (Ontario)	1969/ D-27	Originally the whole tailings area was seeded. Vegetation cover was not uniform due to the heterogenous nature of these tailings. The bare patches were then covered with gravel overburden and reseeded.	Initially vegetation required regular maintenance fertilizer applications but more recently vegetation has become more self sustaining.

PART SIX
PROBLEMS AREAS, RESEARCH AND OTHER NEEDS

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6.0 PROBLEM AREAS, RESEARCH AND OTHER NEEDS

6.1 OVERVIEW

Present practices enable the disposal of very large quantities of tailings while achieving regulatory criteria for protection of the environment. It has also been demonstrated in a number of cases that vegetation can be established on sulphide tailings. However, questions still remain as to the viability of revegetation over the long term. Most importantly the question remains as to whether or not the water quality of seepages and drainages from the reclaimed area will ultimately be acceptable for discharge without further obligations on the part of the mining company or society. At present, these questions cannot be answered with certainty. Therefore, there is a need for further development of the related technology.

There is a need to understand the chemical and physical processes that occur within sulphide tailings as discussed in Section 4.1. Ultimately, this information will enable models to be developed that can be used to predict the behaviour of tailings. This will be beneficial during the planning for new tailings disposal sites and, most importantly, may also provide a basis for the development of at-source abatement methods. The investigation of field scale tailings deposits is essential to the further understanding and development of models of physical-chemical behaviour of tailings. There is sufficient information from theoretical studies and laboratory research to provide a basis for the field scale investigations.

There is a need to consider methods for the dewatering of tailings so as to enable access onto slimes deposits as well as to reduce the period over which tailings are consolidated. Related to this, there is a need to consider the long term physical stability of tailings and tailings dams, particularly as a function of surface and sub-surface hydrological conditions. A knowledge of all factors

affecting the physical stability of the tailings will enable methods, which appear to be attractive as regards to chemical stabilization, to be also evaluated as to their potential effects on physical stability of the tailings disposal area. For example, a method which seals the surface of tailings thereby preventing access of oxygen may lead to physical instability of the saturated tailings due to hindrance of dewatering.

The fact that only the uppermost zone of sulphide tailings appears to be subject to oxidation and acid formation requires further consideration as regards to stabilization. Consideration should be given to "manipulation" of the chemical processes that occur within this zone in order to abate acid formation. For example, extension of the "hard pan" so as to form an impermeable seal may prove to be a potential abatement method. Removal of sulphides from at least those tailings that form the uppermost layer of the tailings disposal area may warrant consideration.

There is a need to definitively assess revegetation as a means of stabilization of sulphide tailings. Field scale deposits of tailings should be monitored so as to determine the effects of revegetation on the physical-chemical processes within the tailings deposit, including the effects on the quality of seepages and drainages. In addition, there is a need to positively demonstrate survival of vegetation without the need for periodic maintenance of the revegetated area.

Stabilization of tailings by disposal underwater has been demonstrated to be very cost effective. There is a need to review the regulatory aspects related to the underwater disposal of tailings, in addition to investigating the environmental implications of this method of disposal.

Technology for the treatment of seepages and drainages from tailings disposal areas is well developed. However, there must be continuing efforts to reduce the quantity and total

acidity of water that requires treatment, and to enable the disposal of sludge as a stable material.

Some specific programs in order to meet the needs outlined above are described below:

1. Select several sulphide tailings disposal areas, on surface and underwater, with and without vegetation, and monitor with respect to areal extent and depth so as to determine the physical chemical processes which have and are presently occurring. Tailings deposits of various "ages" and degree of acid generation should be selected for the study.
2. Describe the physical-chemical processes that occur within tailings and assess the physical-chemical effects resulting from "manipulation" of these processes such as: removal of pyrite, extension of hard pan, addition of inhibitors, reaction to form an impermeable layer, and allowing oxidation to occur to "completion". This program would be followed by bench and then field scale investigations.
3. Prepare a report which considers the interrelationships among geotechnical, hydrological, and hydrogeological factors as a function of the type of tailings disposal system. This report would include consideration of slimes dewatering. This report would be expected to lead to field scale investigations of various types of tailings disposal systems.

Completion of the above programs will provide the understanding necessary to define potential long term stabilization methods for both future and existing tailings deposits. Definition of potential methods should be followed by programs to assess their field scale practicability and associated costs.

In addition to the above major programs, research must continue into the various aspects of revegetation technology, including surface preparation, plant species selection, and methods which ensure long-term perpetuation of the vegetation.

A research and development program to meet the objectives discussed above is described in the following section.

6.2 PROPOSED ACID GENERATING TAILINGS PROGRAM

621 OBJECTIVE

The objective of the proposed program is to further develop techniques that will enable the operation and abandonment of acid generating tailings disposal areas in a predictable, affordable, timely and environmentally acceptable manner.

622 KEY CONCERNS DURING THE LIFETIME OF MINING OPERATIONS

.1 Prior to Operation

During the mine development phase, the developer should be able to more confidently predict various aspects related to the disposal of sulphide tailings. In particular, the developer should be able to:

1. Predict the physical and chemical characteristics of tailings as a function of time and type of disposal scheme.
2. Predict the advantages and disadvantages of various schemes for the disposal of tailings, for both the operating and post-operating phases of the mine development.

3. Predict the hydrogeology of the disposal area prior, during, and subsequent to tailings disposal.

.2 During Operation

During the mine operating phase the operator should be able to operate the tailings disposal area so as to facilitate its eventual abandonment. This objective must be consistent with maintenance of acceptable environmental conditions during the operating phase.

.3 Post-Operation

Following completion of mining activity, the operator should be able to abandon the tailings disposal area in the minimum time and at minimum cost, while ensuring satisfactory physical and chemical stability of the area.

623 SUMMARY - TAILINGS DISPOSAL STATE OF THE ART

Tailings disposal technology is well developed with respect to:

- the construction of dams with minimal risk of structural failures
- the establishment of vegetation on accessible and dormant sulphide tailings, and
- the control of contaminants in effluents (e.g. heavy metals, cyanide and arsenic).

In addition, some information is available concerning:

- the chemistry of tailings reactions
- the relative merits of alternative tailings placement methods, and
- benefits of revegetation.

Less information has been developed with respect to:

- control of acid generation
- long-term physical, chemical, hydrogeological processes and/or changes
- economical techniques for abandonment of tailings disposal areas
- mathematical and/or experimental predictive methodology, and
- management of seepage.

624 RECOMMENDED RESEARCH AND DEVELOPMENT PROGRAM

It is recommended that the following research and development programs be initiated in order to further develop technology for the long term management of acid generating tailings.

.1 Technology Transfer

A series of reports should be prepared, describing current knowledge and providing guidance to mining companies and others. Topics would include relatively well-established technologies. There should be a provision for updating these reports periodically. It is recommended that manuals be developed initially for:

- the revegetation of acid generating tailings
- the design and operation of tailings disposal systems and
- the control of tailings disposal area effluents.

.2 Prediction Techniques

There is a need for better methods to predict the chemical and physical behavior of tailings (acid generation, consolidation...), based on sample parameters and/or experimental evaluations. Longer-term, it would be desirable

to improve water movement models and develop chemical/physical transformation models (with the ultimate goal of integration of the models). It is recommended that programs be carried out to:

- Evaluate experimental techniques and recommend further research to develop methods to predict the degree of acid formation that can be expected due to sulphide mining and tailings disposal operations
- Assess the practicability of using the physical/chemical properties of ore and tailings to predict changes with time (acid generation, leaching, conglomeration, dewatering...).

.3 Tailings Disposal Systems

Better techniques are required for dewatering tailings, both to permit access for placing coverage and to minimize the period of consolidation (continuous weeping of contaminated water). Long term structural stability as well as surface and subsurface hydrological factors (seasonal variations, dispersion patterns, flushing, maximum storms...) need to be better understood. The merits of tailings component segregation (e.g. pyrite) need to be clarified. Also, the role of physical/chemical changes in the system needs to be evaluated (e.g. - whether the formation of hardpan is beneficial or detrimental). It is recommended that programs be carried out to:

- Estimate the costs for current and prospective tailings disposal methods
- Monitor the physical and chemical properties of field scale tailings deposits (i.e. bacterial populations, oxygen levels, seepage, water quality, water content, particulate characteristics, conglomeration tendencies, etc.) for different tailings systems such as:
 - low acid generating, unvegetated

- low acid generating, revegetated
 - high acid generating, unvegetated
 - high acid generating, revegetated.
- Evaluate the merit of alternative cover techniques during operation and post-operation.
 - Evaluate the merits of tailings disposal system designs and operating techniques (pyrrhotite segregation, deposition methods...) with regard to such factors as tailings dewatering, chemical stability of the tailings, physical stability of the tailings and containment dams, ease of rehabilitation, and water control.

.4 Effluent Control

The monitoring, interception and treatment of waters from tailings disposal areas requires continuing attention, as regards to reliability and costs. Improved techniques for reducing the quantity and/or contamination of water (including control of chemical and bacterial oxidation) need to be developed and demonstrated. In-place passive techniques (injection of bactericide or neutralization agent) for both the short and long term treatment of sulphide tailings requires consideration. It is recommended that programs be carried out to:

- develop and demonstrate (laboratory and field scale) methods to decrease the generation of acid (SLS and other bactericides, oxygen and water cut-off techniques, in situ neutralization, simpler and more economic methods for the neutralization and clarification of effluents).

.5 Revegetation

The specific benefits and effects of revegetation need to be quantified. In addition, continued research is required as regards to "soil" preparation, species selection, and long

term self-perpetuation of vegetation. It is recommended that programs be developed to:

- demonstrate the establishment of long-term, maintenance free vegetation
- improve techniques for "soil" characterization, development of resistant plant species (i.e. cold, drought, acid), and techniques that minimize the requirements for borrow materials (clay, soil), and fertilizer.

625 PROGRAM SCHEDULE AND BUDGET

A summary of the recommended projects to meet the requirements discussed in Section 624 is given in Table 6-1. As indicated in Table 6-1, the program could require 3 to 5 years at an order of magnitude cost of \$2.5 million. Examples of typical project outlines are given in Table 6-2.

TABLE 6-1
Recommended Project List Preliminary Budgets
(3-5 Year)

Category	Title	Program Cost	Total
		\$K	\$k
1. Technical Transfer	- Revegetation Manual	50	
	- Tailings Disposal Manual	100	
	- Effluent Control Manual	50	<u>200</u>
2. Prediction Techniques	- Experimental Techniques	200	
	- Prediction Techniques	100	<u>300</u>
3. Tailings Storage	- Costs	100	
	- Monitoring	600	
	- Alternate Covers	50	
	- Alternative Systems	250	<u>1000</u>
4. Effluent Control	- Control of Acid Generation	400	
	- Simplified Neutralization	200	<u>600</u>
5. Revegetation	- Long term Establishment	200	
	- Upgrade Agronomy	200	<u>400</u>
			<u><u>2,500</u></u>

Notes:

1. Budgets shown are contract funds; mine operators' direct and indirect contributions are not included.

TABLE 6-2

Examples of Project Outlines

Category: Tailings Storage Systems
Project: Category 3, Title 1
Title: Costs of Tailings Storage Alternatives
Objective: To determine costs of current and potential technology for Canadian reactive sulphide tailings disposal
Related Work: Pedco study for USBM (1984)
 NUT Program Project UIT 610

Scope:

1. Analyse costs of current practises
2. Estimate costs of prospective practises (liner/capping, etc..)
3. Report results
4. Prepare "how-to" manual

<u>\$/Schedule</u>	<u>84/85</u>	<u>85/86</u>	<u>86/87</u>	<u>87/88</u>	<u>88/89</u>	<u>Total</u>
\$K	50	25	-	25	-	100

Category: Tailings Storage System
Project: Category 3, Title 2
Title: Monitoring of Tailings Disposal Systems
Objective: To assess the physical and chemical status and changes within tailings system
Related Work: USBM coal waste and spoils studies, NUT Program...

Scope:

1. Select several candidate tailings areas representing different disposal methods, reactivities and post-operational treatments
2. Establish gas and water sampling stations
3. Monitor bacterial, chemical, physical properties within and adjacent to the disposal area
4. Evaluate seepage flows and qualities
5. (On selected basis, evaluate acid generation control (see RATS - 3 - 3))
6. Report results
7. Compile and compare in "how-to" manual

<u>\$/Schedule</u>	<u>84/85</u>	<u>85/86</u>	<u>86/87</u>	<u>87/88</u>	<u>88/89</u>	<u>Total</u>
\$K	100	200	250	100	50	600

(Assuming 4 sites)

NOT - National Uranium Tailings Program

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REQ. NO. 3-9041

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VOLUME ONE

SOURCES OF SULPHIDE TAILINGS
AND CURRENT TAILINGS MANAGEMENT
PRACTICES

SULPHIDE TAILINGS MANAGEMENT STUDY

A Joint Project of

Monenco Limited, Cominco Limited, Inco Limited
and Noranda Research

May 1984

Monenco Limited
500 Beaverbrook Court
Fredericton, New Brunswick
E3B 5X4

MICROMEDIA

MAR 15 1985

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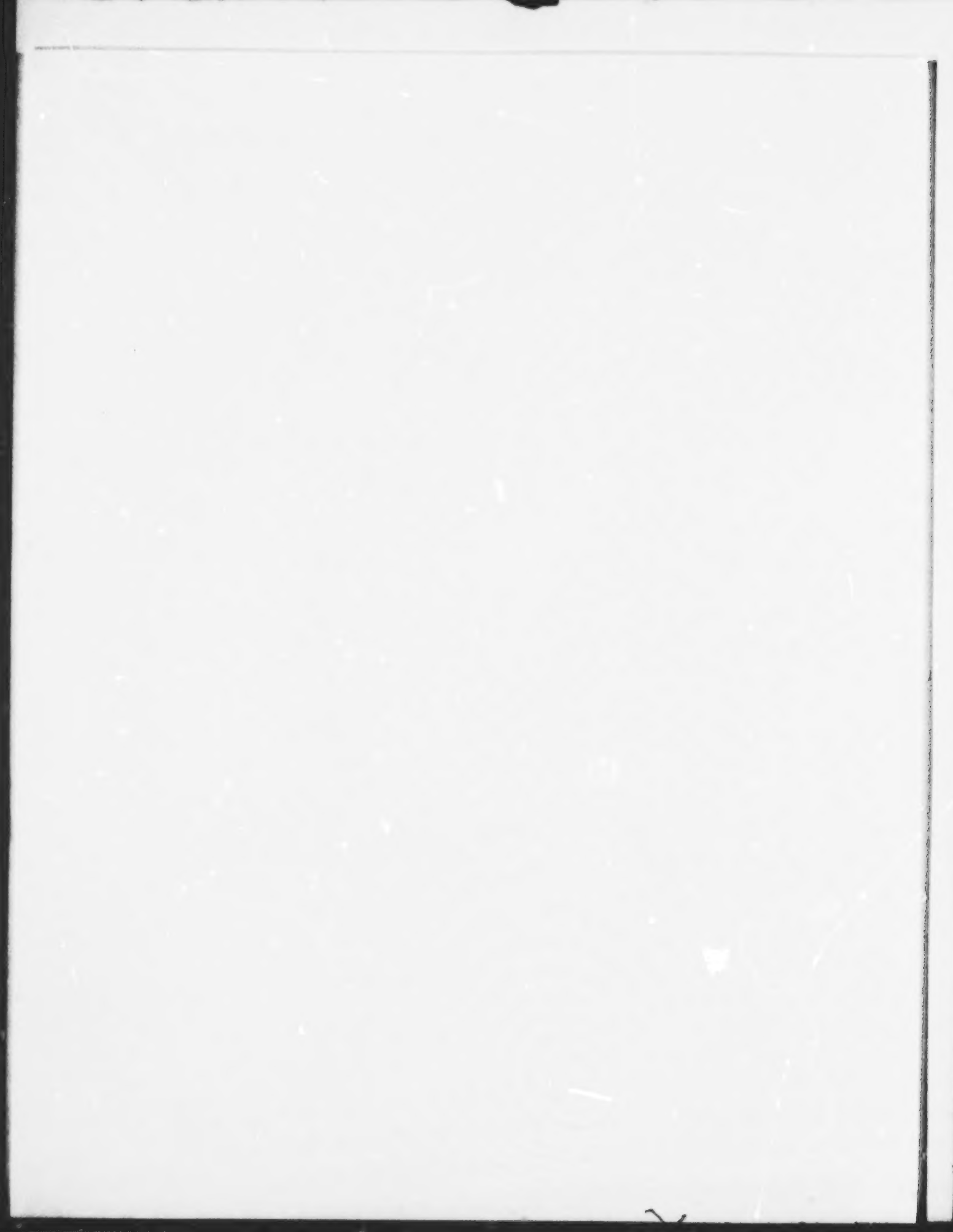
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A

SULPHIDE TAILINGS - New Brunswick

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REF. NO.	MINE NAME/LOCATION/OWNER	MINE STATUS	ORE	SULPHIDE TAILINGS	COMMENTS
	<u>NEW BRUNSWICK</u>				
1.	BRUNSWICK No. 12 - 47° 28' N. 65° 53' W. - BRUNSWICK MINING, & SHELTING CO. LTD	OPERATING SINCE 1964	- RESERVES 50 x 10 ⁶ TONNES EST. TO YEAR 2005 - MASSIVE SULPHIDE LENSES - COPPER, LEAD, ZINC	- 40 x 10 ⁶ TONNES COVERING 607 ha OF TAILINGS POND - FINAL HEIGHT OF TAILINGS TO BE APPROX. 45m	
2.	- HEATH STEELE - 47° 17' N. 66° 05' W. - HEATH STEELE MINES LTD	- OPERATING 1955 to 1958 AND 1962 to 1983	- RESERVES 43.6 x 10 ⁶ TONNES - MASSIVE SULPHIDE LENSES - COPPER, LEAD, ZINC	- 202 ha OF TAILINGS POND - 4.5 x 10 ⁶ TONNES (EST.)	
3.	- ANACONDA - CHIRICO - 47° 34' N. 66° 17' W. - ANACONDA AMERICAN BRASS LTD.	- OPERATED BRIEFLY IN 1971 AND SHUT DOWN SAME YR	- RESERVES 10 x 10 ⁶ TONNES - FINE GRAINED MASSIVE SULPHIDES - COPPER, LEAD, ZINC	- 0.3 x 10 ⁶ TONNES COVERING 5 ha TAILINGS POND AREA	
4.	- WEDGE MINE - NORTHERN N.R. - COMINCO LTD	- OPERATED 1962 to 1968	- FINE GRAINED MASSIVE SULPHIDES - COPPER, LEAD, ZINC	- 0.08 x 10 ⁶ TONNES OF DEVELOPMENT ORE BURIED IN PIT	- AREA HAS BEEN RECLAIMED



SULPHIDE TAILINGS - QUEBEC

PAGE 1 OF 6

REF. NO.	MINE NAME/LOCATION/OWNER	MINE STATUS	ORE	SULPHIDE TAILINGS	COMMENTS
	<u>QUEBEC</u>				
1.	- ALONCO - 78°25' LONG. 49°29' LAT. - EAGLE MINES LTD	- OPERATING SINCE 1974	- RESERVES 1.1 x 10 ⁶ TONNES - PYRITE / PYRRHOTITE - GOLD, SILVER	- 2.5 x 10 ⁶ TONNES COVERING 49 ha TAILINGS POND AREA	
2.	- CAMPELO MINES LTD. - 78°52' LONG. 49°09'20" LAT.	- OPERATING SINCE 1965	- RESERVES 2.1 x 10 ⁶ TONNES - PYRITE / PYRRHOTITE - GOLD, SILVER	- 3.7 x 10 ⁶ TONNES COVERING 55 ha TAILINGS POND AREA	
3.	- CHARPILL RESOURCES LTD - CEDAR RAY & HENDERSON - 78°20' LONG. 49°52' LAT.	- OPERATING SINCE 1965	- RESERVES 9.0 x 10 ⁶ TONNES - 4% PYRRHOTITE - COPPER	- 128 ha TAILINGS POND - 23 x 10 ⁶ TONNES (EST.) - 9 x 10 ⁶ " (PAPER TAILINGS)	- REVEGETATION BEING "ATTEMPTED"
4.	- CHARPILL RESOURCES LTD - 79°02' LONG. 48°15' LAT. - NORANDA	- OPERATING SINCE 1974	- RESERVES 0.56 x 10 ⁶ TONNES - PYRITE - GOLD	- 16 ha TAILINGS POND	- WILL ATTEMPT TO RECLAIM BY COVERING TAILINGS WITH SILICATE RESIDUES
5.	- DORIS GOLD MINE INC. - 78°20' LONG. 48°15' LAT. - SUCRETEO MINERALS LTD	- OPERATED 1978 to 1981	- RESERVES 0.33 x 10 ⁶ TONNES - PYRITE / ARSENOPYRITE - GOLD	- 4.0 ha TAILINGS POND	- PLAN TO REVEGETATE AT COMPLETION OF MINING
6.	- EAST MALARTIC MINES - 78°46'30" LONG. 48°07'30" LAT.	- OPERATED 1981 to 1979	- 2% PYRITE, 8% CALCITE - GOLD	- 18 x 10 ⁶ TONNES COVERING 170 ha TAILINGS POND AREA	- SUCCESSFUL REVEGETATION
7.	- FALCONBRIDGE COPPER - 79°03' LONG. 48°18' LAT.	- OPERATING SINCE 1969	- RESERVES 4.0 x 10 ⁶ TONNES - MASSIVE SULPHIDE - COPPER, ZINC	- 5 x 10 ⁶ TONNES (EST.) COVERING 77 ha TAILINGS POND AREA	- HAVE DONE TEST PLOTS
8.	- FALCONBRIDGE COPPER - 79°58' LONG. 48°47' LAT.	- OPERATING SINCE 1954	- RESERVES 3.8 x 10 ⁶ TONNES - COPPER, GOLD	- 7 x 10 ⁶ TONNES (EST.) 153 ha DRAINAGE LAKE BASIN	
9.	- NORANDA LTD. - NORANDA	- OPERATING SINCE 1952	- RESERVES 185 x 10 ⁶ TONNES - COPPER	- 316 ha TAILINGS POND AREA	

SULPHIDE TAILINGS - QUEBEC

FIGURE 206

REF. NO.	MINE NAME/LOCATION/OWNER	MINE STATUS	ORE	SULPHIDE TAILINGS	COMMENTS
10.	- LAKEAUQUE MINES - TECH CORR	- OPERATING SINCE 1985	- RESERVES 0.86 x 10 ⁶ TONNES - PYRITE - GOLD	- 16 x 10 ⁶ TONNES (EST.) COVERING TAILINGS POND AREA OF 250 ha	- TEST PLOTS
11.	- LAKEAUQUE - 77°36' LONG, 49°06' LAT. - NORTHGATE	- CLOSED 1975	- RESERVES 0.9 x 10 ⁶ TONNES - COPPER, ZINC	- 6 ha TAILINGS POND AREA	
12.	- LOUNDA - 77°31' LONG, 49°06' LAT.	- OPERATING 1970 TO 1978 1990 TO DATE	- PYRITE	- 6 ha TAILINGS PILE - MILLING AT MONTROU BARRE	
13.	- MONTROU BARRE - 77°21' LONG, 49°05' LAT.	- MINE CLOSED - CEMENTATION OPERATING	- PYRITE - COPPER, LEAD, ZINC	- 110 ha TAILINGS POND AREA	
14.	- MONTROU - 77°21' LONG, 49°05' LAT.	- OPERATING SINCE 1963	- RESERVES 0.63 x 10 ⁶ TONNES - 20-40% PYRITE / 6-15% PYRRHOTITE - COPPER, ZINC	- 200 ha TAILINGS POND AREA WHICH USED TO BE WATSON LAKE	- LARGE SCALE REVEGETATION TESTS
15.	- MONTROU SHELTER - 77°21' LONG, 49°05' LAT. - MONTROU	- OPERATING SINCE 1927	- SLAG	- 150 ha TAILINGS POND AREA	
16.	- ORCANAN - 77°21' LONG, 49°05' LAT.	- OPERATING 1963 TO 1982	- COPPER, ZINC	- 0.28 x 10 ⁶ TONNES COVERING 9 ha WATSON LAKE TAILINGS AREA	
17.	- PATRICK - 77°21' LONG, 49°05' LAT.	- OPERATING SINCE 1959	- RESERVES 5.8 x 10 ⁶ TONNES - PYRITE / PYRRHOTITE - COPPER, GOLD	- 50 ha TAILINGS USED AS BACKFILL - TAILINGS POND	
18.	- SIBRA MINES - 77°21' LONG, 49°05' LAT.	- OPERATING SINCE 1887	- RESERVES 0.94 x 10 ⁶ TONNES - GOLD	- 106 ha TAILINGS POND AREA	- SOME TAILINGS AREA REVEGETATED

SULPHIDE TAILINGS - SUPER

PAGE 3 OF 6

REF. NO.	MINE NAME/LOCATION/OWNER	MINE STATUS	ORE	SULPHIDE TAILINGS	COMMENTS
19	- SERRAVALLO - 78°25' LONG. 99°08' LAT. - SERCO INC.	- OPERATING SINCE 1981	- RESERVES 4.72 x 10 ⁶ TONNES - COPPER, ZINC	- 60 ha TAILINGS ROAD AREA	
20	- MARQUELINE MINES - 78°08' LONG. 66°29' LAT.	- OPERATED 1979 TO 1976 AND 1979-1982	- COPPER, SILVER	- 6.8 x 10 ⁶ TONNES TAILINGS IN TAILINGS POND	
21	- LA AME, DIST. OR - 78°25'28" LONG. 98°51'51" LAT. - FERRAZZONI ARGENTARIA INC.	- UNDER EXPLORATION	- RESERVES 0.55 x 10 ⁶ TONNES - 5-10% PYRITE - GOLD	- ORE TREATED AT MARQUELINE	
22	- GORREAROU INC. - 79°01' LONG. 98°11' LAT.	- UNDER DEVELOPMENT	- RESERVES 0.55 x 10 ⁶ TONNES - GOLD	- NO ON SITE ORE TREATMENT	
23	- DOLAN - 78°25'20" LONG. 98°51'51" LAT. - LAC MINERALS INC.	- OPERATING SINCE 1980	- RESERVES 2.2 x 10 ⁶ TONNES - GOLD, SILVER	- 2.0 x 10 ⁶ TONNES (EST) IN TAILINGS ROAD AREA	
24	- BOURQUET - 78°25'16" LONG. 98°51'41" LAT. - LAC MINERALS LTD.	- OPERATING SINCE 1979	- RESERVES 6.9 x 10 ⁶ TONNES - PYRITE - GOLD, SILVER	- NO ON SITE ORE TREATMENT	
25	- KENNESAW - 78°25' LONG. 98°15' LAT. - SUPERIOR MINERALS	- OPERATING SINCE 1981	- RESERVES 0.04 x 10 ⁶ TONNES - PYRITE / ARSENOPYRITE - GOLD, SILVER	- ORE TREATED AT ORBEN (DANIEL)	
26	- KENNESAW GOLD MINES - 77°41'9" LONG.	- UNDER DEVELOPMENT	- RESERVES 1.4 x 10 ⁶ TONNES - GOLD, SILVER		
27	- TERNES ANIERES - 77°15' LONG. 98°50' LAT. - LAC MINERALS LTD.	- OPERATED 1984 TO 1985		- 300 ha TAILINGS ROAD AREA	- CONCENTRATOR ONLY
28	- KIAM GOLD MINES - 77°18' LONG. 98°07' LAT. - ENCANTER INC.	- OPERATING SINCE 1981	- RESERVES 5.2 x 10 ⁶ TONNES - GOLD, SILVER	- ORE TREATED AT LAMARQUE	

SULPHIDE TAILINGS

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REF. NO.	MINE NAME/LOCATION/OWNER	MINE STATUS	ORE	SULPHIDE TAILINGS	COMMENTS
27.	- BORE D'OR - 77°42'00" LONG 98°51'00" LAT. - BOURBON MAINE LTD.	- OPERATING SINCE 1979	- RESERVES 0.91 x 10 ⁶ TONNES - GOLD	- ORE TREATED AT BOURBON	
28.	- FROSTBERG - 77°30'00" LONG 98°08'00" LAT. - BOURBON MAINE LTD.	- OPERATING SINCE 1991	- RESERVES 1.0 x 10 ⁶ TONNES - GOLD	- TAILINGS POND FILL	
29.	- BIRON 2 - 77°30'00" LONG 98°06'00" LAT. - BORE D'OR MAINE LTD.	- UNDER EXPLORATION	- GOLD		
30.	- CALAD - 77°10'00" LONG 98°30'00" LAT. - LAUREN INC.	- UNDER EXPLORATION	- RESERVES 0.54 x 10 ⁶ TONNES - GOLD		
31.	- LAKE SAINT - 76°51'00" LONG 97°55'00" LAT. - FAUCONNIER-DEE COPPER	- UNDER EXPLORATION	- RESERVES 0.63 x 10 ⁶ TONNES - GOLD		
32.	- LAKE BOURBON - 76°01'00" LONG 97°25'00" LAT. - LAKE BOURBON COPPER MAINE INC.	- OPERATING SINCE 1992	- RESERVES 5.6 x 10 ⁶ TONNES - 2% PYRITE - GOLD	- 0.15 x 10 ⁶ TONNES TAILINGS COVERING 7 ha TAILINGS POND AREA	
33.	- CHAMPLAIN - 76°01'00" LONG 97°58'00" LAT. - CHAMPLAIN RESOURCES	- OPERATING INTERMITTENTLY SINCE 1975	- RESERVES 0.19 x 10 ⁶ TONNES - PYRITE - GOLD	- TAILINGS TREATED AT MIRABEL IS AND PLACED IN LAKE DORÉ	
34.	- ALABAMA - 76°10'00" LONG 97°57'00" LAT. - CANADIAN LAKE DEL. INC.	- UNDER EXPLORATION & DEVELOPMENT	- RESERVES 0.10 x 10 ⁶ TONNES - PYRITE / ARSENIC PYRITE - GOLD		
35.	- MARSCHIO - 76°10'00" LONG 97°57'00" LAT. - PHARMEX X LTD.	- UNDER DEVELOPMENT	- RESERVES 0.28 x 10 ⁶ TONNES - PYRITE / PYROMORPHITE		

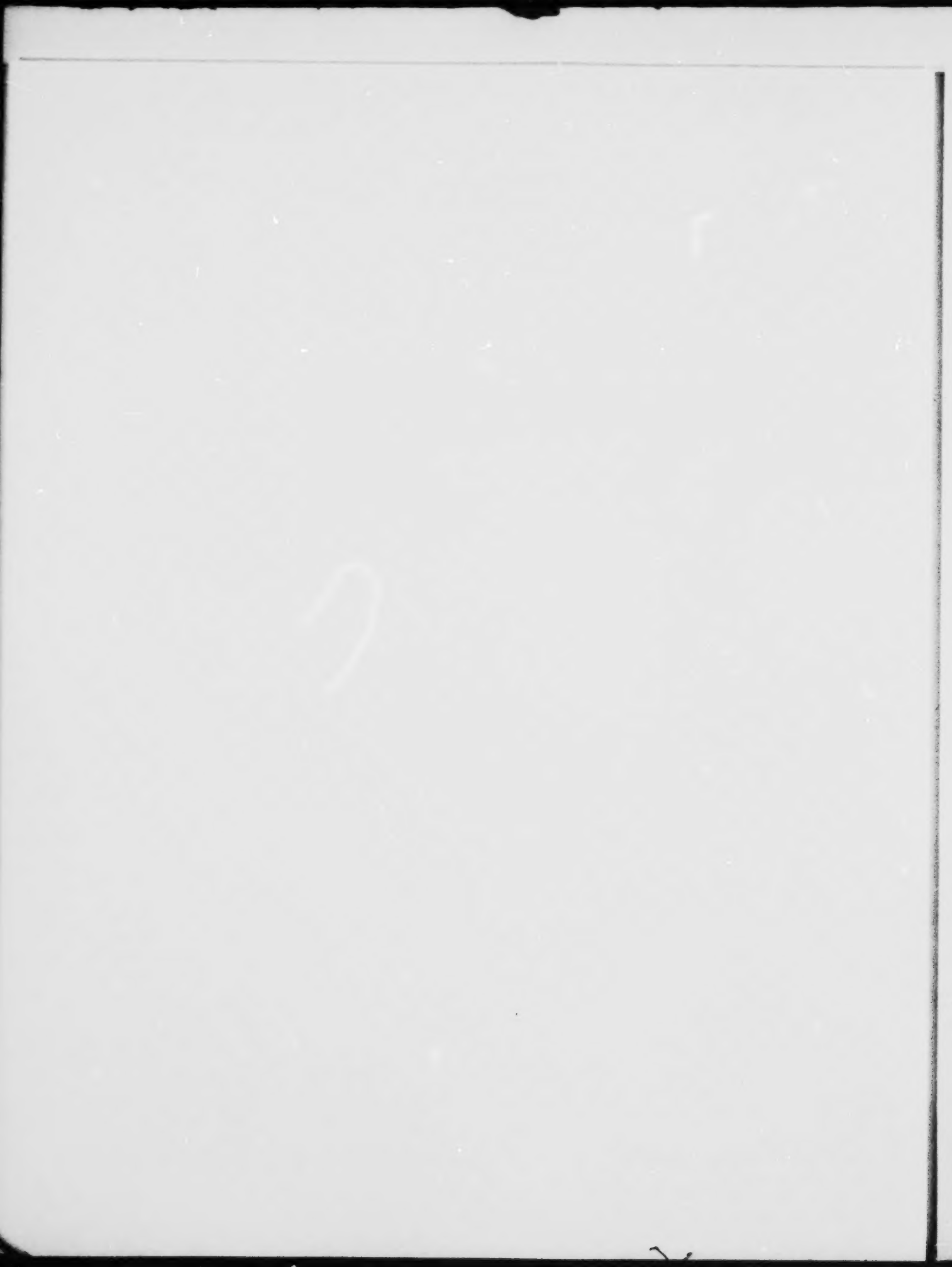
SULPHIDE TAILINGS - QUEREC

REF. NO.	MINE NAME / LOCATION / OWNER	MINE STATUS	ORE	SULPHIDE TAILINGS	COMMENTS
38.	- Canton Resources - 77° 12' 30" W, 98° 15' 30" N LOT - Quebec Miner - Miner Inc.	- DORMANT	- RESERVES 0.009 x 10 ⁶ TONNES - PYRITE - GOLD	- ORE TREATED AT JALANQUA	
39.	- Russian Kid - 77° 12' 30" W, 98° 15' 30" N LOT - Canadian Mines LTD	- DORMANT	- RESERVES 1.2 x 10 ⁶ TONNES - GOLD	- ORE TREATED AT BELMORAL	
40.	- Ulfersbach - 77° 12' 30" W, 98° 15' 30" N LOT - Ulfersbach - Minerals LTD	- OPERATED 1965 TO 1971	- RESERVES 0.9 x 10 ⁶ TONNES - PYRITE - GOLD	- 1.9 x 10 ⁶ TONNES TAILINGS	
41.	- CDR Resources - 77° 12' 30" W, 98° 15' 30" N LOT - Canadian Mines Group LTD	- CLOSED DURING ABANDONMENT	- RESERVES 0.91 x 10 ⁶ TONNES - PYRITE - GOLD		
42.	- Aquatino - 77° 12' 30" W, 98° 15' 30" N LOT - Aquatino Exploration LTD	- CLOSED DURING ABANDONMENT	- RESERVES 0.059 x 10 ⁶ TONNES - GOLD	- < 10 ha TAILINGS TAIL	
43.	- Duaragami Mines LTD - 77° 12' 30" W, 98° 15' 30" N LOT	- DORMANT	- RESERVES 2.6 x 10 ⁶ TONNES - LEAD, ZINC		
44.	- Gault Gold Mines - 77° 12' 30" W, 98° 15' 30" N LOT - Belandier	- ABANDONED	- RESERVES 9.6 x 10 ⁶ TONNES - PYRITE / ARSENOPYRITE - GOLD, SILVER		
45.	- Paurina - 78° 15' 45" W, 99° 13' 45" N LOT - Capella Mines	- DORMANT	- PYRITE / PYRRHOTITE / ARSENOPYRITE - GOLD		
46.	- Paurac - 78° 15' 45" W, 99° 13' 45" N LOT - Canadian Mines Group LTD	- DORMANT			
47.	- Black Cliff Mines - 78° 15' 45" W, 99° 13' 45" N LOT	- DORMANT	- RESERVES 0.3 x 10 ⁶ TONNES - PYRITE - GOLD		

SULPHIDE TAILINGS - QUEBEC

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REF. NO.	MINE NAME/LOCATION/OWNER	MINE STATUS	ORE	SULPHIDE TAILINGS	COMMENTS
48	MINIERIE ALBERTA GARD ALONG Ave C - 77° 05' 20" Long, 49° 09' 30" Lat.	- CLOSED	- RESERVES 1.2 x 10 ⁶ TONNES - PYRITE - GOLD		
49	- ROAD ALBERTA Ave C - 77° 05' 20" Long, 49° 09' 30" Lat. - AFR RESERVES	- DORMANT	- PYRITE - GOLD		
50	- CATT. DES ENTREPRISES DE QUEBEC Ave C - 77° 05' 20" Long, 49° 09' 30" Lat.	- CLOSED AFR	- RESERVES 1.1 x 10 ⁶ TONNES - PYRITE - GOLD		
51	- BURNING Ave D - 77° 05' 20" Long, 49° 09' 30" Lat.	- PROSPECT	- RESERVES 0.5 x 10 ⁶ TONNES - PYRITE - GOLD		
52	- BURNING Ave D - 77° 05' 20" Long, 49° 09' 30" Lat. - McQuinn GARD d'Orphee Mines	- DORMANT	- RESERVES 0.07 x 10 ⁶ TONNES - PYRITE - GOLD		
53	- BURNING Ave E - 77° 05' 20" Long, 49° 09' 30" Lat. - McQuinn Mines	- DORMANT	- RESERVES 0.09 x 10 ⁶ TONNES - PYRITE - GOLD		
54	- GARD GARD BERT Ave E - 77° 05' 20" Long, 49° 09' 30" Lat.	- UNDER EXPLORATION	- RESERVES 0.46 x 10 ⁶ TONNES - PYRITE / PYRRHOTITE - GOLD		
55	- GARD - BURNING Ave E - 77° 05' 20" Long, 49° 09' 30" Lat. - CAMPING RESERVES	- DORMANT (NEVER IN Production)	- RESERVES 0.85 x 10 ⁶ TONNES - PYRITE - GOLD		
56	- GARD Ave E - 77° 05' 20" Long, 49° 09' 30" Lat.	- CLOSED			
57	- JAC ALBAIN Ave E - 77° 05' 20" Long, 49° 09' 30" Lat. - SIDA	- DORMANT (DORMANT OFF ON 3-DEC-1985)	- RESERVES 0.5 x 10 ⁶ TONNES - PYRITE / PYRRHOTITE	- 12 ha TAILINGS POND	



SULPHIDE TAILINGS - ONTARIO

PAGE 1012

REF. NO.	MINE NAME/LOCATION/OWNER	MINE STATUS	ORE	SULPHIDE TAILINGS	COMMENTS
	<u>ONTARIO</u>				
1.	- LAMAR LAKES DIVISION - LAMAR LAKES - ALBERTA MINES LTD.	- OPERATING	- RESERVES 2.15 x 10 ⁶ TONNES - LEAD, ZINC	- 0.56 x 10 ⁶ TONNES	
2.	- STURGEON LAKE AREA - NEW ONTARIO - MATTHEW MINES LTD.	- OPERATING SINCE 1972	- RESERVES 3.7 x 10 ⁶ TONNES - COPPER, LEAD, ZINC	- 4.0 x 10 ⁶ TONNES COAL 160 ha TAILINGS DISPOSAL AREA	
3.	- GECO DIVISION - MANITOUBA - ALBERTA MINES LTD.	- OPERATING SINCE 1957	- RESERVES 3.7 x 10 ⁶ TONNES - COPPER, LEAD, ZINC	- 16 x 10 ⁶ TONNES (EST.) COVERING 130 ha TAILINGS DISPOSAL AREA	
4.	- KID CREEK MINE - TAILINGS - KID CREEK MINES LTD.	- OPERATING SINCE 1966	- RESERVES 8.7 x 10 ⁶ TONNES - COPPER, LEAD, ZINC	- 20 x 10 ⁶ TONNES (EST.)	
5.	- DUL CREEK - TAILINGS - KID CREEK MINES LTD.	- OPERATING SINCE 1972	- RESERVES 0.96 x 10 ⁶ TONNES - GOLD	- 0.22 x 10 ⁶ TONNES (EST.)	
6.	- MACASSA DIVISION - KIRKLAND LAKE AREA - LAC MINERALS LTD.	- OPERATING SINCE 1933	- RESERVES 2.0 x 10 ⁶ TONNES - GOLD	- 4.0 x 10 ⁶ TONNES (EST.)	
7.	- SUDBURY DIST. MINES - SUDBURY - INCO LIMITED		- COPPER, NICKEL	- 2400 ha TAILINGS DISPOSAL AREA	- 2400 ha REVEGETATED OVER LAST 30 YEARS
8.	- FALCONBERG - SUDBURY AREA - FALCONBERG LTD.	- OPERATING SINCE 1930	- COPPER, NICKEL	- 25 x 10 ⁶ TONNES (EST.)	
9.	- LAMAR LAKES - TAILINGS - ALBERTA MINES LTD.	- OPERATED IN 1970'S	- GOLD	- 45 ha TAILINGS DISPOSAL AREA	

[illegible]

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SULPHIDE TAILINGS - BRITISH COLUMBIA

PAGE 1 OF 4

REF. NO.	MINE NAME/LOCATION/OWNER	MINE STATUS	ORE	SULPHIDE TAILINGS	COMMENTS
	<u>BRITISH COLUMBIA</u>				
1.	- SAG GROUND - 10° 16' LONG. 59° 11' LAT. - EMERY SILVER MINES	- OPERATING	- RESERVES 200 x 10 ⁶ TONNES - PYRITE / ARSENOPYRITE - GOLD, SILVER	- 200 x 10 ⁶ m ³ OF TAILINGS COVERING 230 ha TAILINGS POND AREA	- REMEDIATION TEST PITS
2.	- LUNA MOUNTAIN HILL PACE - 10° 16' LONG. 59° 11' LAT. - WESTERN RESOURCES	- OPERATING SINCE 1975	- RESERVES 107 x 10 ⁶ TONNES - MASSIVE PYRITES - COPPER, LEAD, ZINC	- 2.2 x 10 ⁶ TONNES TAILINGS (50% BACKFILL & 50% INTO BUTTE LAKE)	
3.	- BELL - 10° 19' LONG. 58° 00' LAT. - ALZADA	- OPERATING SINCE 1972	- RESERVES 102 x 10 ⁶ TONNES - 8-15% PYRITE - COPPER	- 41 x 10 ⁶ TONNES COVERING 175 ha TAILINGS POND AREA	- 100% SULPHIDES
4.	- GIBBOLTAZ - 10° 17' LONG. 58° 21' LAT. - GIBBOLTAZ MINES LTD.	- OPERATING SINCE 1972	- RESERVES 200 x 10 ⁶ TONNES - PYRITE - COPPER	- 500 ha TAILINGS POND AREA	- 10 ha RECLAIMED
5.	- GOLDSTREAM - 50 km N. of TAILINGS - ALZADA	- PROSPECT	- RESERVES 35 x 10 ⁶ TONNES - PYRITE - COPPER, ZINC	- 1.7 x 10 ⁶ TONNES COVERING 25 ha TAILINGS POND AREA	- REMEDIATION TEST PITS
6.	- CANOLA - 10° 13' LONG. 58° 30' LAT. - CONVENTER CANADA MINES	- PROSPECT - PLANNING STAGE	- RESERVES 36 x 10 ⁶ TONNES - PYRITE / Hg - GOLD	- 28.5 x 10 ⁶ m ³ OF TAILINGS	
7.	- BATTANNA - 10° 18' LONG. 59° 36' LAT. - COPPER RESEARCH ENTERPRISES LTD.	- OPERATED 1955-1974	- MASSIVE SULPHIDES - COPPER	- 97 x 10 ⁶ TONNES TAILINGS	
8.	- GRANT MASCOT - 10° 18' LONG. 59° 38' LAT. - GRANT MASCOT MINES LTD.	- OPERATED 1955 TO 1959 (NOT 1974) - 1955 TO 1974	- PYRIMITE - COPPER, NICKEL	- 9.7 x 10 ⁶ TONNES COVERING 20 ha OF SWAMP LAND	
9.	- GRANDUC - 10° 21' LONG. 58° 13' LAT. - CANADA WINE MINES	- OPERATING SINCE 1967	- PYRIMITE - COPPER	- 2.6 x 10 ⁶ TONNES TAILINGS IN BRASSER RIVER	

REF. NO.	MINE NAME/LOCATION/OWNER	MINE STATUS	ORE	SULPHIDE TAILINGS	COMMENTS
10.	- GRAMISEL - 126°08'5" LONG. 59°36.5' LAT. - NAD 1983	- OPERATED 1966 TO 1972	- CHALCOPYRITE - COPPER	- 150 x 10 ⁶ TONNES TAILINGS CHIEFLY 76% TAILINGS DISPOSAL AREA	- INERT SULPHIDES
11.	- SULLIVAN - 126°08' LONG. 59°42' LAT. - CANADIAN	- OPERATING SINCE 1910	- RESERVES 40 x 10 ⁶ TONNES - PYRITE / PYRRHOTITE - LEAD, ZINC	- 115 x 10 ⁶ TONNES TAILINGS CONTAINED BY DAMS (ULTIMATE HT. OF 25m)	- EXTENSIVE REVEGETATION RESEARCH
12.	- BENSON LAKE MINE - 125 km E. OF PORT ALICE - B.A. CHEMICAL CO.	- OPERATED 1962 - 1973	- RESERVES MINIMAL - CHALCOPYRITE / PYRRHOTITE	- 2.0 x 10 ⁶ TONNES IN BENSON LAKE	- MINIMAL OXIDATION OBSERVED
13.	- BLUEBELL MINE - 98.3 km N.E. OF NELSON - CANADIAN	- OPERATED 1961- 1961 & 1952 - 1971	- PYRRHOTITE	- 1.9 x 10 ⁶ TONNES IN KOOTENAY LAKE (DEPTHS OF 11 TO 120m)	- MINIMAL OXIDATION OBSERVED
14.	- LORNE - 121°08' LONG. 59°27' LAT. - LORNE MINING CORP.	- OPERATING SINCE 1972	- RESERVES 407 x 10 ⁶ TONNES - PYRITE	- 105 x 10 ⁶ TONNES IN VALLEY TAILINGS FILL	
15.	- ERICKSON - 129°38' LONG. 59°13.5' LAT. - ERICKSON GOLD MINING CORP.	- OPERATING SINCE 1979	- GOLD, SILVER	- 0.2 x 10 ⁶ TONNES	
16.	- ISLAND COPPER - 127°28.3' LONG. 60°34' LAT. - UTAH MINES LTD.	- OPERATING SINCE 1971	- CHALCOPYRITE - COPPER	- 194 x 10 ⁶ TONNES IN HUBERT INLET	
17.	- IDAHO - 121°18' LONG. 59°31' LAT. - CANADIAN MINES LTD.	- OPERATING SINCE 1982	- PYRITE	- 0.95 x 10 ⁶ TONNES	
18.	- CHATELLE - 127°06' LONG. 57°17' LAT. - DORVILLE MINING LTD.	- OPERATING SINCE 1971	- CHALCOPYRITE / PYRITE	- 0.06 x 10 ⁶ TONNES	

SULPHIDE TAILINGS - BRITISH COLUMBIA

REF. NO.	MINE NAME/LOCATION/OWNER	MINE STATUS	ORE	SULPHIDE TAILINGS	COMMENTS
19.	- DUTHIA - 20 Km W. OF SARNTERS - SILVER STANDARD MINES	- CLOSED	- ARSENOPYRITE		
20.	- TETRA - 127°14.8' LONG. 55°01.9' LAT. - VIRGINIA SILVER MINES LTD.	- MINER PENDING	- PYRITE / ARSENOPYRITE	- 0.02 x 10 ⁶ TONNES	
21.	- BREIDA MINES - 120°00.5' LONG. 49°53' LAT. - BREIDA MINES LTD	- OPERATED 1970-1993 (NO RECORD ANY)	- RESERVES 110 x 10 ⁶ TONNES - CHALCOPYRITE / PYRITE	- 97.2 x 10 ⁶ TONNES COVERING 399 ha TAILINGS POUD AREA	- INERT SULPHIDES
22.	- DUSTY MINE - 119°22' LONG. 49°21' LAT. - DUSTY MINE MINES LTD	- OPERATED 1970-1976	- CHALCOPYRITE / PYRITE	- ORE MINED AT HORN SILVER	
23.	- HORN SILVER - 119°41' LONG. 49°03.4' LAT. - DANKOE MINES	- OPERATED 1979-1981	- CHALCOPYRITE	- 0.05 x 10 ⁶ TONNES	
24.	- TAMBORVILLE COPPER MINE - 120°33' LONG. 49°20' LAT. - NEWMOUNT MINES	- OPERATING SINCE 1972	- RESERVES 143 x 10 ⁶ TONNES - CHALCOPYRITE	- 80.5 x 10 ⁶ TONNES	
25.	- GOAT - 127°33.6' LONG. 54°20.5' LAT. - AIR-QUEST RESOURCES LTD.	- OPERATED 1979-1981	- PYRITE	- 0.005 x 10 ⁶ TONNES	
26.	- PREMIER - 130°01' LONG. 54°03.5' LAT. - BRITISH SILVER PIONEER MINES	- CLOSED	- CHALCOPYRITE	- 4.3 x 10 ⁶ TONNES	
27.	- TASU - 132°08' LONG. 52°06.5' LAT. - WESTBROOK MINES (FRESHWATER)	- OPERATED UNTIL 1983	- RESERVES 0.4 x 10 ⁶ TONNES - CHALCOPYRITE	- 10.3 x 10 ⁶ TONNES	

SULPHIDE TAILINGS - BRITISH COLUMBIA

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REF. NO.	MINE NAME/LOCATION/OWNER	MINE STATUS	ORE	SULPHIDE TAILINGS	COMMENTS
28.	- OTTAWA - 117°29' LONG. 49°21.5' LAT. - SUREN DEVELOPMENT	- CLOSED		- 0.006 x 10 ⁶ TONNES	
29.	- SEQUENTIA - 117°28.6' LONG. 49°21.3' LAT. - DAVID MINERALS LTD.	- OPERATED 1975 - 1979	- PYR. FE	- 0.015 x 10 ⁶ TONNES	
30.	- LOTICA - 117°27' LONG. 49°21.5' LAT. - DAVID MINERALS LTD.	- CLOSED	- SILVER, LEAD, ZINC		
31.	- BLUE BIRD - 117°28' LONG. 49°20' LAT. - ROSS ISLAND MINING CO.		- PYR. FE / ARSENOPYRITE	- 0.004 x 10 ⁶ TONNES	
32.	- BLUE JACK - CALLAGHAN - 123°08' LONG. 59°09' LAT. - VAN SILVER MINES	- OPERATED 1976 - 1977	- PYR. FE	- 0.008 x 10 ⁶ TONNES	
33.	- WARMAN - 123°06' LONG. 50°08' LAT. - NORTHAIR MINES LTD.	- SUSPENDED 1982	- PYR. FE	- 0.05 x 10 ⁶ TONNES	

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SULPHIDE TAILINGS - NORTHWEST TERRITORIES

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REF. NO.	MINE NAME/LOCATION/OWNER	MINE STATUS	ORE	SULPHIDE TAILINGS	COMMENTS
	<u>NORTHWEST TERRITORIES</u>				
1.	- REARIS MINE - LITTLE CARIBOUNIS IS. - COMINCO LTD.	- OPERATING SINCE 1982	- RESERVES 10 x 10 ⁶ TONNES - LEAD, ZINC	- 0.5 x 10 ⁶ TONNES (EST.)	
2.	- NANISILIK - STRATHCONA SOUND - NANISILIK MINES LTD.	- OPERATING SINCE 1976	- RESERVES 4.4 x 10 ⁶ TONNES - LEAD, ZINC	- 3.0 x 10 ⁶ TONNES (EST.)	
3.	- LUPIN MINE - 400 Km N.E. OF YELLOWKNIFE - ECHO BAY MINES LTD.	- OPERATING SINCE 1982	- RESERVES 3.5 x 10 ⁶ TONNES - GOLD	- 0.24 x 10 ⁶ TONNES (EST.)	
4.	- SILVER BEAR MINE - 43 Km S. OF PORT RAVEN - TERRA MINES LTD.	- OPERATING SINCE 1976 & SINCE 1977	- COPPER, SILVER	- 0.4 x 10 ⁶ TONNES (EST.)	
5.	- CARL RYAN MINES - NEAR YELLOWKNIFE - COMINCO	- OPERATING SINCE 1977	- RESERVES 1.9 x 10 ⁶ TONNES - GOLD	- 1.0 x 10 ⁶ TONNES (EST.)	
6.	- GIANT MINE - W. SIDE YELLOWKNIFE BAY - GIANT YELLOWKNIFE MINES LTD.	- OPERATING SINCE 1989	- GOLD	- 7.4 x 10 ⁶ TONNES (EST.)	
7.	- CULLATAN LAKE - 6.2 Km N. OF THOMPSON, AB - CULLATAN L. GOLD MINES LTD.	- OPERATING SINCE 1983	- RESERVES 0.3 x 10 ⁶ TONNES - GOLD	- 0.09 x 10 ⁶ TONNES (EST.)	
8.	- PINE POINT - S. SIDE GREAT SLAVE L. - PINE POINT MINES LTD.	- OPERATING SINCE 1964 - 1983	- RESERVES 70 x 10 ⁶ TONNES - LEAD, ZINC	- 200 x 10 ⁶ TONNES (EST.)	

B

7

Tailings Management Study: Sullivan Mine

Part Two: Extent of Sulphide Tailings

1. Location: Kimberley, B.C.
Latitude 49° 42'N
Longitude 116° 00'W
2. Owner: Cominco Ltd.
200 Granville Street
Vancouver, B.C. V6C 2R2
3. General Layout (Topographic) of Mine and Mill Site

Kimberley is situated in the foothills of the Purcell Mtn. range in southeastern British Columbia. The mine is located on south to east facing mountain slopes above Mark Creek approximately 3.5 km north of the city centre. Mine surface workings are between elevations 1,190 m and 1,585 m. Cominco has worked the Sullivan orebody since 1909.

The concentrator is located some 5 km. south of the mine in a transition zone between the Purcell Mtn. and Rocky Mountain Trench physiographic regions between elevations 1,010 m. and 1,070 m. Cominco has operated the concentrator since 1923.

The environmental setting of the mine and concentrator sites are described in Table 1.

4. Ore Reserves: In excess of 125 million tonnes ore mined since 1910. Reserves at end 1982, 44 million tonnes. Currently mined at approximately 2 million tonnes/year.

General Composition of Orebody

The orebody is 2,135 m. long, from several m. to 90 m. thick, and roughly resembles an inverted saucer. The strike is north-south, and the dip averages about 30° to the east, gentle in the upper part of the mine, steepening in the central portion, and flattening along the eastern edge.

The orebody occupies one limb of a north-plunging anticline, the crest of the anticline coinciding approximately with the western margin of the orebody. It occurs in the lower Proterozoic Aldridge formation, which in the Kimberley area is composed of at least 4,500 m. of alternating argillites, siltites and dirty quartzites. The Aldridge is the lower member of the 10,700 m. thick Purcell group of sediments.

It contains a high proportion of turbidite-type beds and is thought to represent the early basin filling of the Purcell geosyncline.

In the lower section of the mine, stratigraphy in the ore zone is very regular, with bands of sulphides interbedded with bands of barren rock, and sedimentary structures are preserved in great detail. In the upper portion of the mine, this delicate layering is only present in very small areas, large areas of massive ore occur, and there are large zones of essentially pure iron sulphide with little or no lead or zinc. The upper zone also varies broadly from place to place, with confused streaking or banding in some locations and no internal structure in others.

The principal sulphides are pyrrhotite, sphalerite, galena and pyrite. Chalcopyrite and arsenopyrite are minor constituents. Magnetite is fairly common in some parts of the orebody, and cassiterite is present in small amounts. In the oxide zone, cerrusite and pyromorphite are common.

5. Mining and Ore Beneficiation

5.1 Mining

Early mining was by open stoping in very competent ground. Pillars left in this part of the mine were quite irregular due to selective mining of high grade lead ore. A more orderly stoping pattern was adopted after development of differential flotation permitted extraction of mixed, lower grade lead-zinc ores.

Open stoping left extensive openings in the mine and large unsupported areas. As a safety measure against hanging wall collapse, and accompanying air blasts, backfilling using surface gravel commenced in 1935 and continued until 1961. Backfilling of the lower, more regular stopes, using the float reject from the sink-float plant at the concentrator, started in 1949. For several years, pyrrhotite tailings were added to the float fill to cement and consolidate it. This practice was discontinued when problems of oxidation and production of excessive heat and sulphur dioxide gas arose. Subsequent filling of stopes using untreated float continued until 1973.

Current mining is by pillar recovery using a combination of slusher systems and modern mechanized mining methods. Because the pillar size and the mining environment vary greatly throughout the mine, a number of mining methods have been tried over the years. These range from a single slot and shell to a multi-stage slot, core and shell, and to a method of successive slot and shell stages.

Large scale multi-stage mining resulted in large tonnages of broken ore remaining within the pillar while subsequent stages were being developed and drilled. With ores of certain mineral compositions, this prolonged exposure to air and confinement within the pillar, together with the presence of groundwaters, was conducive to rapid oxidation, heating and generation of sulphur dioxide gas. Current mining methods are aimed at eliminating this problem by reducing the scale of operation such that each stage can be developed and extracted independently, thus reducing the time of exposure of broken ore to circulating air.

Pillar recovery incorporates controlled subsidence of hanging wall waste into stoped-out areas causing the most extensive type of land disturbance at the mine. In 1979 it became necessary to backfill a number of subsidence caves to improve control of air and water entry to underground and to prevent surface venting of sulphur dioxide produced by oxidation of pyrrhotite.

5.2 Ore Benefication

The Sullivan Concentrator commenced operation in 1923 following the development of a successful differential flotation process capable of separating the complex ore into lead, zinc, iron and tin concentrates. Lead and zinc concentrates are shipped to Cominco's smelter in Trail, B.C. Tin concentrates are exported. A portion of the iron concentrate is used to produce sulphuric acid as an intermediate to phosphate fertilizers manufactured at Cominco's fertilizer plant also located at Kimberley.

Crushing

All ore is crushed underground at the mine. Primary crushers are located at 790 and 850 m. levels and the main crushing plant at the 1,160 m. level.

The crushed ore is conveyed to an 10,000 tonne underground storage bin above the 1130 m. level transportation system. From the underground storage bin the ore is transported by electric trains 6 km. to the concentrator.

A bin blasted from bedrock provides 2,900 tonnes of live ore storage at the concentrator.

Primary Concentration - Heavy Media Separation

The primary stage of concentration utilizes the difference in specific gravity between waste rock and valuable ore. Two parallel bath separators contain a dense slurry made up of high-grade galena concentrates and water. Waste rock floats on the slurry surface, effectively rejecting about 35% of ore tonnage treated. The reject "float" rock assays approximately 0.2% Pb, 0.2% Zn and 5.5% Fe.

The float rock is conveyed to storage on the float pile which is estimated to contain 7 million tonnes of rock. Production of float rock can be as high as 4,500 tonnes per day, but averages about 2,300 tonnes per day over the year.

Significant quantities of float rock are hauled away each year for use as railway ballast, landfill and road construction.

Secondary Concentration - Selective Flotation (Pb & Zn)

The ore tonnage retained after heavy media separation is wet ground to a fine pulp using conventional rod mill/ball mill methods. Approximately 1,700 tonnes of steel grinding media are consumed each year to grind the ore to a nominal size of approximately 90% passing 75 micrometers.

Concentrates of lead and zinc are produced using a complex selective flotation process. Lead concentrates contain approximately 86% of the available lead metal and 8% of the available zinc metal. Zinc concentrates recover approximately 5% of the available lead metal and 84% of the available zinc metal, received from the mine.

The selective flotation process utilizes the following reagents:

<u>Reagent</u>	<u>Tonnes/Yr.</u>
Lime (CaO)	4,200
Xanthate (NaIX)	170
Copper sulphate (CuSO ₄)	1,300
Sodium cyanide (NaCN) ⁴	120
Frothers (Dowfroth, MIBC, Pine Oil)	40

Tertiary Concentration - Iron and Tin Recovery

The slurry which is rejected after lead and zinc recovery is conditioned with sulphuric acid. Selective flotation is then used to produce an iron concentrate which assays approximately 52% iron and 33% sulphur. A portion of this concentrate is treated at the fertilizer operation to recover sulphur.

The iron flotation circuit utilizes the following reagents:

<u>Reagent</u>	<u>Tonnes/Yr.</u>
Sulphuric acid (H ₂ SO ₄)	4,300
Xanthate (NaIX)	110
Aero promoter 404	220

The iron concentrates not utilized for sulphur recovery become the iron tailing. This slurry when combined with scavenger concentrates assays approximately 48% iron and exits the plant at a pH of 6. Although the tonnage of iron tailing can be as high as 1,600 dry tonnes/day (4,700 litres/min.), average over the year is 1,000 dry tonnes/day (3,000 litres/min.).

The slurry which was rejected after iron recovery is diluted with water and passes over inclined rubber decked "blankets" which trap the heavy tin-bearing mineral cassiterite (SnO₂). A concentrate is produced after upgrading on shaking tables to assay approximately 35% tin. The reject tailing from the gravity recovery circuit of the tin plant assays approximately 19% iron and exits the plant at a neutral pH. The reject tailing are stored in the "siliceous" tailing ponds, which are separate from the "iron" tailing pond. Although the tonnage of solids reporting to the siliceous tailing ponds can be as high as 2,700 tonnes/day, the average over the year is approximately 1,700 tonnes/day.

6. Description of Tailings Disposal System

a) Topographic and Subsurface Characteristics of the Tailings Disposal Areas

Iron and siliceous tailing disposal areas are situated on a generally well drained glacio fluvial plain. Topography is gently undulating with slopes of 2% to 5%. Tailing deposits are underlain by gravelly (gsl-gs) fluvial deposits with a shallow surface veneer (30 cm) of fine to medium textured (si-s) aeolian material. Soil parent material was derived from fine to coarse grained non-calcareous gravels.

b) Quantity of Tailing Contained in Areas

Iron Tailing: present - 40 million tonnes
future - 45 million tonnes

Siliceous Tailing: present - 75 million tonnes
future - 85 million tonnes

c) Physical Layout and Characteristics of Tailings Deposit

Iron Tailing

The iron tailing storage consists of two areas, the old iron tailing pond (storage prior to 1965) which covers approximately 130 ha. and the current active pond of approximately 100 ha. Included in the inactive pond is a sloping area along the north perimeter of the pond of approximately 30 ha. with only a shallow tailing cover of 30 cm to 120 cm.

Within the main disposal areas tailing depth ranges up to 25 m. Average depth estimated at 9 m.

A discontinuous hard "ferruginous" cap has developed at or near the surface throughout most of the inactive area. The oxidation zone is characterized by a change in tailing colour from grey-black to red-orange and varies in thickness from 15 cm. to 45 cm. The hard, cemented "cap" generally occurs at the contact between oxidized and unoxidized tailing. Salts generally accumulate on the underside of this impermeable layer. A zone of dry to moist grey tailing with a blocky structure and of variable thickness generally occurs between the oxidized layer and saturated unoxidized tailings. Saturated, unoxidized iron tailing have been described as thixotropic and are unstable with insufficient bearing strength to support equipment.

The active pond has a surface covered by recently deposited unoxidized tailings and water. Mine drainage and tailing effluent are stored within this pond area prior to treatment and release to the St. Mary River.

Siliceous Tailing

The siliceous tailing storage ponds currently consist of two active areas (i.e. #2 & #3 in the attached diagram) and an inactive emergency pond (#1). Once the tailing depth in ponds #2 & #3 increases to the same elevation as pond #1, the active disposal area will incorporate the inactive pond and will be modified to function as two ponds. Total area occupied by siliceous tailing approximates 140 ha. Tailing depth ranges up to 25 m. in the inactive pond.

Oxidation of siliceous tailings results in a colour change from dark grey to red-orange. Unlike iron tailing an impermeable ferruginous cap does not form and oxidation normally occurs to a greater depth. Hard platy layers several mm. thick occur throughout the oxidized zone. Unoxidized siliceous tailing drain more readily than iron tailing, are stable and can support heavy equipment working on the surface.

d) Ratio of Flooded to Exposed (Tailing) Areas During the Deposition Period

Iron tailing: 1:10
Siliceous tailing: 1:10

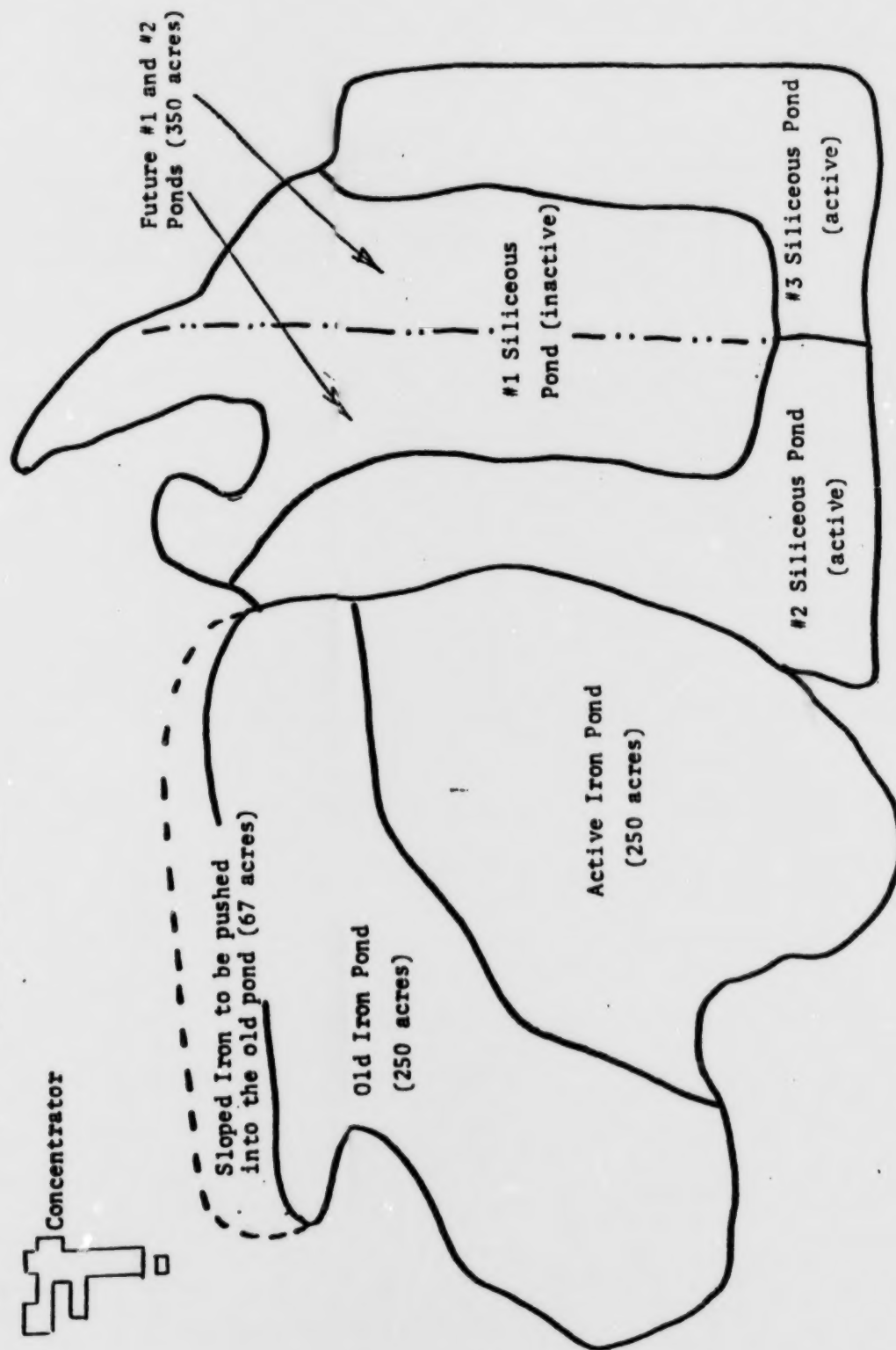
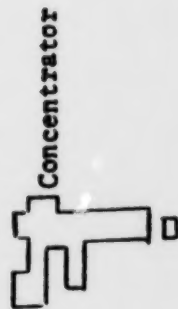
e) Method Used to Contain Tailing

Pre-1975: Tailings were conveyed through launders set on trestles of a desired height on the centre line of the proposed dams. Tailing was distributed along the length of the dam through holes in the bottom of the launder. Tailing from these holes was distributed by alternately placed short V-shaped cross launders, extending a few feet on either side of the main launder. During the initial stages of building the dam, the pulp flowing towards the outer side was impounded by a low auxiliary dam. This system of distribution resulted in the building of wide crest dams with gently sloping faces.

Post-1975: In 1975 new 8 m. high perimeter dykes, 1,280 m. and 975 m. long were built below the iron and siliceous tailings ponds to replace the old dykes which were of questionable stability. At the same time, the new dykes provided additional storage

COMINCO LTD.
Sullivan Concentrator

TAILING POND AREA



capacity for siliceous tailings.

The new dykes are built with compacted coarse siliceous tailings and contain two filter drains constructed from pit run gravel and screened sand with a 6 inch clay tile drainage pipe inside. Upstream and downstream slopes are two horizontal to one vertical and 2 1/2 horizontal to one vertical, respectively. The dykes are raised periodically using compacted siliceous tailings conveyed to the site by bottom dump scrapers.

Ultimate height of perimeter dyke is 25 m.

f) Method Used to Place Tailings Into Containment Areas

1. Current Practice

Iron tailing is transported to storage by a system of 30 cm. scclair pipe (1,840 m), 25 cm. sewer pipe (920 m) and 20 cm. sewer pipe (670 m) across a total distance of 3,430 m. The pipeline reduces to 25 cm. and 20 cm. along the perimeter dyke where 7.5 cm. diameter spigots distribute the tailings away from the dyke face. The vertical drop from concentrator to pond surface is approximately 70 m. and pipe gradient is minimized by the use of vertical concrete pressure boxes. Clear water is decanted through vertical towers and remotely controlled valves which are directed by the Drainage Water Treatment Plant.

The siliceous tailings is similarly transported to storage by a system of the following pipes:

35 cm. diameter scclair pipe -- 1,880 m.

40 cm. diameter scclair pipe -- 975 m.

Series of 30,25,20 cm. sewer pipe -- 1,000 m.

Tailings are simiarily spigotted along the perimeter dykes. Water is conveyed out of the pond by the use of floating decants, which pass water to the Drainage Water Treatment Plant.

2. Past Practice

Prior to use of pipe, iron tailing was transported by a system of 5,700 ft. of main launders and 14,250 ft. of side launders. The siliceous system had 6,000 ft. of main and 14,100 ft. of side launders. Grade of the launders was 1 2/3% for iron tailings and 1 1/4% for the siliceous tailings.

Laundry construction was 2" x 12" bottoms and 1" x 12" sides. These were supported on trestles made from pole timber, cut and framed in the adjacent bush. A short piece of 2" x 12" under each pole acted as a mud fill; a piece of 2" x 6" was used as a header on each bent, to support the laundry and a 2" x 12" plank walkway. Tailing was distributed through holes in the bottom of the laundry with alternately placed V-shaped cross launders extending a few feet on either side of the main laundry.

After settling the clarified water was decanted through decant towers inside the pond into ditches and a vitrified clay tile pipe system carried the water to the receiving stream.

g) Surface Drainage and Groundwater Control Methods

Surface drainage and groundwater seepages from upstream of the tailings ponds drain into the iron and siliceous ponds. An interceptor ditch constructed across the slope north of the tailing ponds does not function effectively as a collector of surface drainage and shallow groundwaters.

7. Extent to which Tailings Disposal Area used as part of Mine/Mill Effluent Treatment System

Iron and siliceous tailing ponds are used to store mine drainage and effluents and regulate their discharge to the Drainage Water Treatment Plant. Major dyke upgrading was required with lifts designed for the safe retention of about 2 m. of additional hydraulic load.

The objectives of the pond storage system include:

- 1) provide about 800×10^6 L capacity for the control of peak freshet volumes,
- 2) permit treatment plant shutdowns for maintenance,
- 3) permit some degree of "blend-optimization" of the different strength decants,
- 4) allows levelling of strength fluctuations, and
- 5) improves suspended solids control.

Remote control valve assemblies in the decant structures allow full flow control from the treatment plant and prevent fluctuations that would otherwise be caused by relatively small head changes.

8. Generation, Treatment and Disposal of Seepages and Other Drainages from the Tailings Disposal Area(s)

Seepage water downstream of the tailing disposal areas is not collected or treated. Surface streams are monitored periodically. Groundwater flow patterns, volumes and quality have not been adequately studied. Similarly, the impact of seepages from tailing ponds, the gypsum pond, the calcine pond and cooling pond on local groundwater characteristics has never been thoroughly investigated.

9. Reclamation Measures (past, present, planned)

An intensive revegetation research program has been active on disturbed land and waste disposal sites since 1973. Purpose of the program is to develop effective and practical site preparation and revegetation methods which stabilize waste disposal site surfaces against wind and water erosion, minimize contamination of surface drainage waters, reduce volumes of mine drainage and tailings effluent requiring treatment, improve the aesthetics of the mine and mill area as well as rehabilitate disturbed land and waste disposal sites to a land use compatible with adjacent undisturbed areas.

Due to the extreme phytotoxic nature of acid waste rock and tailings, progress toward development of revegetation techniques has been slow. In addition, since the Sullivan Mine is operational most waste disposal sites are in active use and will remain active for many years. Implementation of operational scale reclamation will be deferred until revegetation techniques have been proven effective and waste disposal areas have been abandoned.

Detailed information related to the tailing revegetation research is presented in Part V.

10. Environmental Concerns Specific to Each Tailings Deposit

a) Iron Tailing Deposit

- physical stability of tailing deposit,
- surface drainage contamination,

- groundwater contamination,
- effluent treatment requirements following abandonment,
- rehabilitation to self-sustaining land use compatible with surroundings,
- vegetation quality and impact on domestic animals and wildlife.

b) Siliceous Tailing Deposit

- air quality and dust control,
- surface drainage contamination,
- groundwater contamination,
- effluent treatment requirements following abandonment,
- rehabilitation to self-sustaining land use compatible with surroundings,
- vegetation quality and impact on domestic animals and wildlife.

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RTG/jb

December 8, 1983

Table 1: Environmental Setting of Sullivan Mine and Concentrator

	Sullivan Mine	Sullivan Concentrator
<u>Elevation (m)</u>	1190-1585 m	1010-1070 m
<u>Physiographic Region</u>	Purcell Mtn.	Transition from Purcell Mtn. to Rocky Mtn. Trench.
<u>Vegetation Subzone</u>	Interior western hemlock - western red cedar zone and subalpine Engelmann spruce - alpine fir zone; subzone with Interior Douglas fir integrating with Interior Douglas fir zone, subzone lacking ponderosa pine on lower east facing slopes.	Interior Douglas fir zone with the moister subzone lacking seral ponderosa pine integrating with the drier subzone with seral ponderosa pine at lower elevations on fluvial deposits
<u>Parent Material and Landform</u>	Complex of deep fine to medium texture (cl-l) moraine and shallow medium to moderately coarse texture (gl-gsl) colluvium at higher elevations with deep, gravelly (gsl-gs) fluvial deposits with significant fine to medium texture (cl-l) moraine at lower elevations; generally non-calcareous.	Deep medium to fine texture (sl-c) moraine grading into gravelly (gsl-gs) fluvial deposits with a shallow surface veneer (30 cm) of fine to medium textured (si-s) aeolian material. Morainial deposits strongly calcareous; fluvial deposit non-calcareous.
<u>Bedrock Groupings</u>	Argillite and siltstone at higher elevations; fine to coarse grained gravels at lower elevations.	Limestone and dolomite for morainial deposits; fine to coarse grained non-calcareous gravels for fluvial deposits.
<u>Topography</u>	Complex moderately to strongly rolling at higher elevations; strongly to extremely steeply sloping at lower elevations.	Gently to moderately rolling at higher elevation grading into gently undulating fluvial plain.

Table 1 (continued)

	Sullivan Mine	Sullivan Concentrator
<u>Soil Development</u>	Orthic dystric brunisol, luvisolic humo-ferric podzol and podzolic grey luvisol at higher elevations; orthic eutric brunisol at lower elevations.	Brunisolic grey luvisol and orthic grey luvisol on morainal deposits at higher elevations; orthic eutric brunisol, orthic dystric brunisol, orthic melanlic brunisol on fluvial and morainal deposits at lower elevations.
<u>Land Use Capability</u>	Moderate yield forest. Undisturbed land currently sustains a forest of lodgepole pine, Douglas fir, western larch, cottonwood, trembling aspen and alder.	Native range. Undisturbed land currently sustains an open coniferous forest dominated by ponderosa pine with significant Douglas fir and a ground cover of shrub and grass species.

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December 8, 1983

Tailings Management Study - Part III Information

Sullivan Operations, Kimberley, B.C.

3.1 Pre-Operation Phase

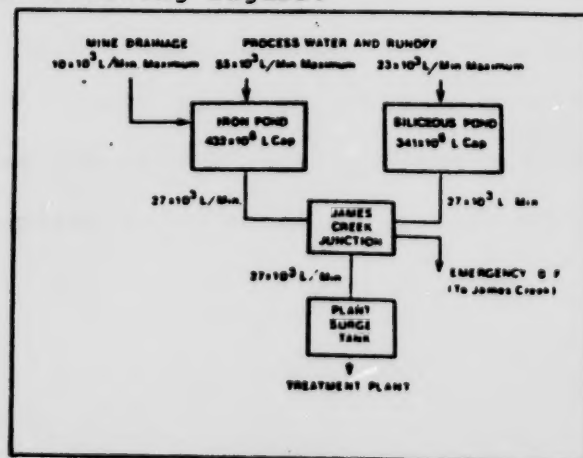
There is no evidence that the problems associated with the long term management of sulphide rich tailings were considered prior to the start of concentrator operations in 1923. It is highly unlikely that any baseline monitoring or environmental planning was conducted at the time. The disposal site utilized immediately below the concentrator was selected for its convenience. Tailings could be laundered on a trestle system without the need for pumping to a more secure disposal area.

This approach was certainly not restricted to the Sullivan development and it likely prevailed in most mines brought into operation prior to the time of environmental awareness. An example of the lack of long term perspective held in those days is that tailings were placed on an area with underlying groundwater flows. As a consequence, a fresh water spring still emerges within the pond and contributes to the overall tailings water management requirement.

3.2 Operating Phase

The immediate objectives of tailings management from the Sullivan are the secure disposal of both siliceous and iron (pyrrhotite) tailings and the effective control of contaminated effluent generated in the respective ponds including mine drainage which is introduced into the iron pond. Details of the ponds and the rationale for the segregated storage of tailings material are provided in Section II of the report.

Various measures have been implemented in recent years to improve the reliability of the ponds and these include the construction of improved dykes and other facilities in 1979 to permit the ponds to function as an integral part of an effluents management system. In prior years, the dykes were such that decand pool volumes had to be minimized at all times as a safety measure. The present effluents management capability provides substantial storage capacity and flow attenuation and is illustrated in the following figure:



Drainage Water Flow Management

In 1983, operation of the old decant towers and underlying clay tile piping was discontinued in favour of a decant pumping and surface piping system which conveys decant around areas requires for present and future tailings disposal. This change was made because the security of the former decant system was questionable and its failure by, for example, the collapse of piping underneath the ponds, could cause disastrous consequences.

These improvements and others of a less major nature have been and continue to be made as part of an overall program undertaken to essentially retrofit an old, unreliable system to a modernized impoundment suitable for present and future conditions. Naturally, it is impossible to rectify all of the past problems of which the most severe is the substantial area of the deposit.

Regulatory Setting

Tailings impoundment is conducted under a bond-enforced Reclamation permit issued by the B.C. Department of Mines which has, as the essential requirement, the rehabilitation of disturbed lands occupied by the tailings deposit. In other words, revegetation of the tailings surface will have to be effected to improve the aesthetics of the area, minimize present environmental problems and restore natural productivity which is appropriate to the area.

An important interim requirement of the permit is the annual demonstration, in the form of progress reports, that satisfactory work and planning is underway so that effective operational reclamation measures will be in hand when the property is permanently shutdown. Research and pilot studies have been underway since 1973 and these are discussed in Section V of this report.

The other important permit affecting the impoundments is the effluents discharge permit under the Waste Management Branch of B.C. Prior to 1979 water quality specifications were applied to the two tailings ponds decants and the mine drainage as separate streams. Since the implementation of the comprehensive management/treatment system, however, quality limitations are only placed on the treatment plant discharge. Nevertheless, the tailings ponds contribute about 60% of the soluble metals and acidity loading being handled in the treatment plant and this is a major issue to be dealt with on property closure as well as being an important cost factor at present.

Although the reclamation and effluent permits are separate regulatory entities, Cominco views the two issues as being essentially one when the operations are terminated.

Thus, surface reclamation is seen as a key in the reduction of metals loadings in drainages from the tailings areas although it is not absolutely clear that present technology will achieve both objectives. It may well be possible to achieve a viable surface "dressing" which satisfies the reclamation requirements but still be faced with the prospect of treating drainages in perpetuity under stipulations of the effluent discharge permit.

Reclamation Programs

As previously noted, reclamation studies on the Sullivan tailings have been underway since 1973. These have clearly demonstrated the phytotoxic nature of the tailings, particularly that of the pyrrhotite deposit. No direct surface revegetation is successful without substantial lime amendments and their application sustained. Top dressing with a significant thickness of soil or overburden has been found to be essential and the superior approach entails the incorporation of a hydraulic barrier of coarser material as an intermediate layer. Waste gypsum from the separate fertilizer production facilities can substitute for topsoil as the growth medium. The research and field trial efforts are discussed more fully in Section V.

Experimental work has proven that a technically effective but costly methods for surface revegetation now exists but there has been no demonstration that such procedures will achieve the more important objectives of controlling the problem leaching reactions. It is evident that obtaining this proof

requires larger and carefully controlled operational trials. Other than the revegetation programs, there have been no studies conducted at the Sullivan to evaluate alternate forms of reclamation such as chemical stabilization of the reactive tailings.

It has been estimated that upon property closure, the complete operational reclamation of the tailings ponds would require a capital expenditure in excess of \$10 million with continuing operating cost for some time. Recognition is currently being given to the fact that the deferral of reclamation to closure may have two serious deficiencies. First of all, the cost burden in a situation where revenues are not being generated is obviously problematic. Secondly, deferral would be a gamble as only operational reclamation on a staged basis can eliminate technological uncertainties and allow for improvements in procedures to be subsequently incorporated.

There are presently permanently inactive areas of the iron pond and these will rapidly increase in size as closure in 20-30 years is approached. A plan is now being developed whereby the -3/16 in. to 3/4 in. fraction of sink/float rejects will be stored on a stable and inactive part of the pond. This material can later be spread to a suitable thickness to serve as the hydraulic barrier for surface revegetation. Although a commitment has not yet been made, it is hoped that the float storage plan will lead to operational reclamation trials

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in the upper areas of the pond in the near future.

Sections 3.3 and 3.4

(The Sullivan situation has been covered in this respect in Section 3.2).

WJKuit/jb

January 11, 1984

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Tailings Management Study - Part II Information

Bluebell Mine Operation of Cominco Ltd.

1. The Bluebell Mine is located in southeastern B.C. on the east side of Kootenay Lake approximately 30 air miles northeast of Nelson, B.C.
2. Cominco was the owner of the property from 1930 on and during its major period of operation from 1952 to 1971 and this status has continued to the present. Several other owners conducted smaller scale operations at the site upon which mineralization was first discussed in about 1820.
3. The mine is located on a promontary of land protruding into Kootenay Lake. The surface directly above the mine workings is steep and rocky with the community of Riondel being in close proximity. Scenic and rugged mountains rise up a short distance from the site.
4. The mine is permanently closed but the known mineralized material remaining underground is about 400,000 tons assaying approximately 5% Pb, 6% Zn and 1.4 oz/ton Ag. Most of this ore can be termed "unrecoverable".

The lead-zinc ore occurred as heavy sulphide replacements in a limestone host rock with the economic minerals being galena and marmatiferous sphalerite. Pyrrhotite was the most abundant sulphide and often occurred in large separate chimneys within ore shoots in addition to being associated with galena and sphalerite. In general, the orebody was highly oxidized and secondary minerals such as anglesite, cerussite and smithsonite were common.

The typical production ore graded 5% Pb, 6% Zn and 21% Fe.

5. During Cominco's period of operation from 1952-1971, production from the mine averaged about 700 tons per day. Open stoping and cut-and-fill stoping were the main mining techniques employed. The proximity of the mine to the lake caused problems and mine water pumping requirements were as high as 6,000 gpm. Thermal springs were also encountered underground.

Ore hoisted to the surface was processed in a conventional flotation process and the filtered concentrates were shipped to the smelter in Trail, B.C. without being dried. The tailings were deslimed by double cycloning and the underflow utilized as mine backfill. The slimes, averaging about 200 tpd were discharged to Kootenay Lake.

Prior to Cominco's operation, the Canadian Metal Company between 1908 and 1921 operated a jig concentrator and the zinc rich tailings from this process were also discharged to the lake. Only a lead gravity concentrate was recovered at this time.

6. Authorization to implement tailings disposal to Kootenay Lake was obtained from the then British Columbia Game Department in January, 1951. No monitoring conditions were specified at the time and the only requirement was that the department be advised of any significant changes in the system.

From 1952 to 1970, the 200 tpd of tailings fines at about 8% pulp density were simply discharged at about 2 m. depth in the lake where the total depth was about 11 m. At times, this resulted in substantial surface turbidity and in 1970 the system was modified to include a surface deaeration device and a 7 m. downspout into a total water depth of 17 m. This substantially reduced fines pluming and turbidity as measured by Sechi disk readings.

No chemical monitoring data is available on lake water quality during the tailings discharge period and the nature and extent of the subsurface deposit is unknown. However, from the method utilized and the tailings properties, it is expected that the solids were widely dispersed. About

90% of the solids mass were particles of less than 325 mesh in size. The material assayed about 0.4% Pb, 0.5% Zn and 24.0% Fe and it is estimated that about 1,500,000 tons of tailings were discharged to the lake from 1952-1971.

From time to time there has been interest in the recovery of the jig tailings from the previous operation (1908-1921) as this material assays about 1.5% Pb, 5% Zn and 33% Fe. Surveys of the bottom indicate that the bulk of the 500,000 ton deposit is confined to an area of about 125 m. square under approximately 120 m. water depth. Recent metallurgical testwork on recovered samples have demonstrated that the sulphides are intact and that little or no oxidation has taken place in the up to 75 years since the material was deposited.

7. The tailings disposal system was not a part of the mine or mill effluent treatment system. Mine drainage flows of up to 6,000 gpm were discharged to the lake separately. Since this water was extremely hard, polyphosphate concentrations of 3-4 mg/L were added underground to control scale development in piping. Later on this was substituted by an organic softening agent as a result of environmental concerns. Heavy metals from tailings and the mine drainage were not regarded as a problem during the period of the Cominco operation.

8. Reclamation activities at the property were initiated in 1977 and satisfactorily completed in 1980 under the terms of the B.C. Department of Mines Permit No. 77 issued in 1972. A total of 5.25 hectares of surface disturbance were reclaimed of which 4.9 hectares were waste rock dumps and 0.2 hectares were tailings, primarily resulting from surface spills.

The main objective of the plant was the improvement of the aesthetics of the site as the abandoned operation was essentially in the midst of a valuable recreation area. The surface demolition and complete removal of old buildings was an important part of the work carried out.

Waste dump areas were regraded and satisfactorily revegetated without encountering significant chemical problems. Much of the tailings area was "cemented" and had obviously been subject to substantial oxidation of sulphides. This material was covered with 0.5 m. thickness of native overburden on fines rich waste rock. Vegetation was satisfactorily established on the covering and sustained with maintenance fertilizer applications.

9. There are no known environmental concerns associated with the lake disposal of tailings from the Cominco operation or the previous one dating back to 1908. Any detrimental environmental impacts during the course of operations appear to have been short-lived and mainly

the result of tailings fines suspension in the lake water.

It is highly significant that the sulphide rich jig tailings (33% Fe) have remained intact over the years since their discharge. Evidently, lake disposal can produce satisfactory long term environmental results as the alternative of surface impoundment would, in this case, almost certainly produce a sustained leaching problem.

WJKuit/jb

December 21, 1983

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Tailings Management Study - Part II Information

Benson Lake Operation of Coast Copper Co. Ltd.

1. The Benson Lake Mine is situated on the north end of Vancouver Island, some 220 air miles north of Vancouver, at the southeast corner of Benson Lake, nine air miles east of Port Alice and 25 miles from Port McNeill, B.C. by road.
2. The mine operated from 1962 to 1973 under the ownership of Cominco Ltd. (through Coast Copper Co. Ltd.). The present owner of the property is the British American Chemical Co. Ltd., a subsidiary of Turbo Resources.
3. The mine is situated in rugged terrain with little or no topsoil or overburden in the area. The surface complex is located on the east facing slope in the Benson River valley at 150 m. elevation and about 3 km. from Benson Lake. Moderate winter temperatures are a feature of the area but it is subject to a high annual precipitation of about 320 cm.

Prior to the start of the operation, it was evident that there was no suitable location in the vicinity for the conventional surface impoundment of tailings. In November, 1961, authorization was obtained from the Federal Department of Fisheries for the mine to utilize Benson Lake for tailings disposal subject to several conditions. The lake and river system in the area is illustrated in the attached Figure 1.

4. The present ore reserves are minimal and would not support a viable operation. Ore depletion was the main factor in the permanent closure of the operation in January, 1973.

The ore zone of the mine was in a relatively thin limestone unit varying from 2 to 6 cm. in thickness. Mineralization was of the skarn type and the economic minerals were chalcopryite and, to some extent bomite. Gold and silver values were present in the chalcopryite and the average grade of the mined ore was about 2.0% Cu. Magnetite was also recovered for a period of time.

The ore contained about 6% chalcopryite, 15% magnetite and 10% pyrrhotite and the major gangue minerals were garnet epidote and calcite.

5. The mine produced an average of 800 tons ore per day by a combination of track and trackless techniques. Access to the orebody was through a 2,000 m. long decline and several levels in the ore zone were worked by conventional open stope procedures.

Ore delivered to the mill was placed in a 600 ton cap. coarse ore storage bin, subjected to two stages of crushing and stored in an 800 ton cap fine ore bin. From there it was milled and a copper concentrate (60 tpd) grading 25% Cu produced in a conventional flotation circuit. Concentrates were dried to about 8% moisture and trucked to Port McNeill for shipment to Japan.

6. The 740 tpd tailings produced in the mill graded about 0.1% Cu and contained the following principle components:

Garnet	39%	Calcite	5%
Epidote	32%	Pyrrhotite	4%
Magnetite	12%	Pyrite	0.5%
Fledspar	5%		

The typical particle size distribution was as follows:

+ 100 mesh	11.0%
-100 + 150 mesh	15.0%
-150 + 200 mesh	11.7%
-200 + 325 mesh	22.3%
-325 mesh	40.0%

The material, as a 30-35% pulp density slurry, was pumped the 3 km. distance for disposal in Benson Lake. The surface plan of the 83 hectare area lake and its general bathymetry are illustrated in Figure 2.

A flocculant solution was prepared in the mill and pumped in a small separate line for addition to the tailings slurry prior to its discharge to the lake. A deaeration device was employed over a vertical downspout discharge extending to about the 30 m. depth which was about 12 m. from the lake bottom. Improvements were made in this system during the course of the operation and until shut-down in January, 1983, about 2.1 million tons of tailings were discharged to the lake.

In addition to the primary lake disposal, a small back-up surface impoundment area was utilized when problems were encountered with the lake system. About 100,000 tons of tailings had been accumulated in this disposal area when the operation was closed.

Mine drainage flows averaging about 1,400 L/min. were discharged to the Benson River near the surface plant site after being percolated through waste rock to reduce residual suspended solids levels. This water was generally slightly alkaline and of excellent quality with respect to heavy metals concentration.

A lake and river monitoring system was implemented at the outset of the operation in 1962. This included water quality sampling in Benson Lake and the surrounding river system and turbidity measurements at two main lake stations. In addition, supplementary sediment surveys in the lake and the analyses of fish specimens were conducted by Department of Fisheries personnel.

Monitoring results generally demonstrated that the tailings disposal operation was satisfactory from the environmental perspective although some controversy persisted over the apparent transport and disposal of extreme fines. It was accepted that the productivity of lake benthic communities had been largely diminished by inundation from tailings fines. Surface turbidity values were low during the summer months as a result of a pronounced thermocline but increased during the winter when classical isothermal conditions developed in the lake.

Biological and water quality sampling demonstrated that the lake disposal operation had only slight impacts at most. Fish tissue metal concentrations were found to be within the normal range of specimens taken from other lakes and streams in B.C. The attached table provides an illustration of typical water quality data from Benson Lake and adjacent rivers. It is apparent that only total iron values in the lake were increased over the comparable stream concentrations.

7. Not applicable to this disposal operation.
8. Drainage from the emergency surface disposal imoundment was discharged to the Benson River when it was necessary to utilize this area. No sampling data is available on this effluent but it is expected that contamination by heavy metals was low since the normal tailings water was alkaline and soluble metals concentration were only slight at most.
9. Reclamation activities at the property commenced in 1972 in accordance with the terms of a permit issued by the B.C. Ministry of Mines (Permit No. 63). These focussed on the waste rock and emergency tailings areas and had the general objective of improving growth conditions on waste disposal and other disturbed areas so as to encourage the regeneration of native vegetation. This work, discussed more thoroughly in Part V of this report, was reasonably

successful on the waste rock materials but not so on the small surface impoundment of tailings.

Conditions in the waste, although certainly less than ideal, were not fundamentally detrimental to the sustenance of vegetative growth as a result of acidic leaching conditions. The waste which is essentially mineralization host rock was slightly alkaline in nature from its significant calcite content.

The situation in the tailings was found to be quite different although calcite, in a given total tailings sample, was present in sufficient quantities to counterbalance the oxidation of pyrrhotite. Vegetative growth could not be maintained in the more coarse grained (beach) area of the deposit as a result of extreme acidity, accumulation of salts and formation of an impermeable, cemented layer near the tailings surface. However, conditions were found to be much more favourable in the slimes area of the deposit. Evidently the segregation of sands and slimes during discharge resulted in a concentration of the more friable alkaline minerals along with the slimes.

Reclamation activities at the site were terminated in 1978 when most of the areas of land disturbance were sold and a dispensation from continuing reclamation responsibilities was obtained from the Ministry of Mines. Reports from a

recent visual inspection indicate that there has been at least some invasion of natural species in the problem tailings area. Perhaps, this is a result of the favourable climactic conditions combined with a diminishment of acid leaching conditions.

10. The Environmental Protection Service conducted a study¹ of Benson Lake in late 1973, approximately one year after the tailings disposal operation was terminated. It was found that lake conditions were satisfactory and that turbidity values were markedly improved with the observation that past operational suspended solids were not attributable to tailings particles. A significant conclusion reached in the study was that heavy metals values bound in the tailings solids were essentially permanently fixed and not being assimilated in the biological food chain.

This satisfactory situation contrasts markedly with experience in the reclamation of the surface tailings deposit. In the latter case, the combined effects of mineral segregation and atmospheric exposure contributed to the demonstrated acid leaching conditions. Although the experience from this operation is limited in depth, it confirms that the initial decision to implement lake disposal was ratified in the environmental perspective.

References

1. R. Hallam, R. Kussat and M. Jones, "A Biological Assessment of Benson Lake following Cessation of Deep Lake Tailings Disposal", Surveillance Report EPS 5-PR-74-2, July, 1974.

WJKuit/jb

December 19, 1983

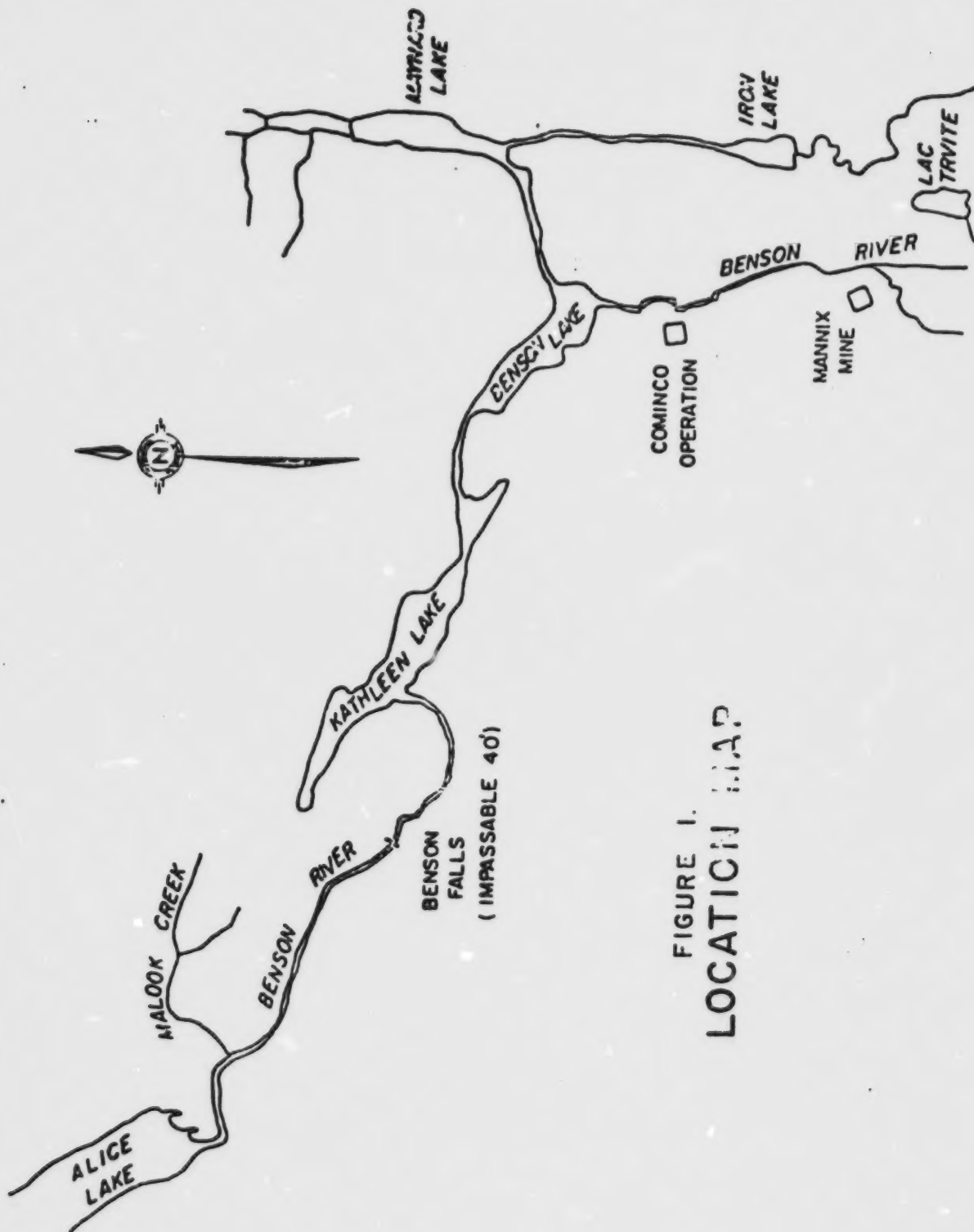


FIGURE 1.
LOCATION MAP

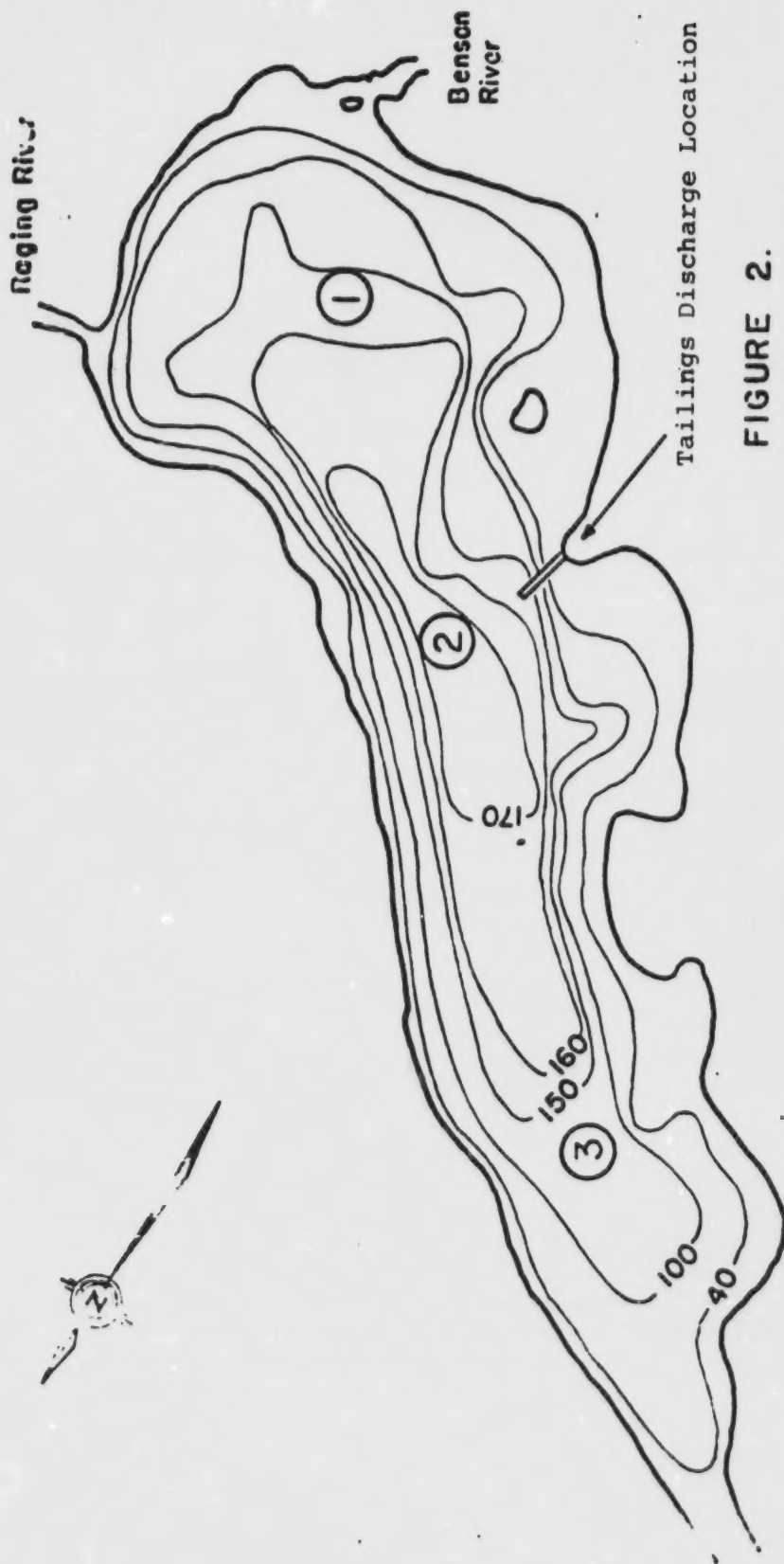


FIGURE 2.
DENISON LAKE
APPROX. SCALE 1"=1100'

WATER QUALITY DATA - BENSON LAKE

SAMPLING DATE - DECEMBER 2, 1971

	mg/l			
	<u>Racing River</u>	<u>Benson River</u>	<u>Station C Benson Lake</u>	<u>Station B Benson Lake</u>
pH	7.3	7.7	7.5	7.5
Turbidity: JCU	12	6	11	11
SS	1	1	1	1
TDS	31	39	34	31
Alkalinity: (as CaCO ₃)	22	34	24	25
Hardness: (as CaCO ₃)	20	35	22	22
Na	0.56	0.66	0.66	0.60
K	0.10	0.14	0.10	0.14
Ca	6.2	13.6	8.0	8.0
Mg	0.90	0.72	0.76	0.76
SiO ₂	3.2	4.0	2.8	2.1
SO ₄	3	2	2	2
Cl	3.2	2.8	2.7	2.5
Fe: Total	<0.05	0.05	0.20	0.20
Dissolved	<0.05	<0.05	<0.05	<0.05
Pb	<0.01	<0.01	<0.01	<0.01
Zn	0.01	0.01	0.01	0.01
Cu: Total	0.005	0.005	0.005	<0.005
Dissolved	<0.005	<0.005	<0.005	<0.005
As	<0.005	<0.005	<0.005	<0.005
Sb	<0.01	<0.01	<0.01	<0.01
Hg: Total	<0.00005	<0.00005	<0.00005	<0.00005
Dissolved	<0.00005	<0.00005	<0.00005	<0.00005

- Note:
1. Parameters are dissolved unless otherwise indicated.
 2. Water quality good; classed as very soft water.
 3. Very slight increase in total iron level in lake; otherwise heavy metal values are normal.

Waste Control
January 28, 1972

10

FACTORS TO BE CONSIDERED IN THE DESIGN OF
TAILINGS DISPOSAL AND RECYCLE SYSTEMS

A PAPER PREPARED FOR THE MINING EFFLUENT
REGULATIONS GUIDELINES TECHNOLOGY TRANSFER SEMINARS

Sudbury, Ontario
Montreal, Quebec
Banff, Alberta

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December 9-10, 1975

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FACTORS TO BE CONSIDERED IN THE DESIGN OF TAILINGS DISPOSAL AND RECYCLE SYSTEMS

ABSTRACT

Federal Government regulations and guidelines for the control and treatment of waste waters from mining/milling operations have been developed based on best practicable technology. Such controls were developed through a task force made up of representatives from federal and provincial agencies and industry. Great care in the location and design of tailings disposal areas and the maximum application of water recycle was considered by the task force to be the best practicable approach to reduce or eliminate the need for formal treatment of effluent waters. Two actual case studies are presented for illustration of best practicable technology.

INTRODUCTION

Late in 1972 the Water Pollution Control Directorate of Environment Canada established a National Effluent Regulations Task Force in order to develop uniform effluent limits for mining operations nation-wide. The task force made up of representatives from federal and provincial governments and industry was responsible for identifying the extent to which discharges from mining operations could be controlled by the application of best practicable technology, and for assisting Environment Canada in drafting suitable effluent regulations and guidelines based on the best practicable technology revealed.

It is the purpose of this seminar to make available to the mining community much of the information and technology collected by the task force and outline the procedures followed in developing the resulting mining effluent regulations and guidelines. It is the purpose of this paper to outline some practical considerations (Best Practicable Technology) in the selection of tailings disposal sites and recycle systems - considerations that can play a significant role in achieving national mining effluent quality requirements.

BEST PRACTICABLE TECHNOLOGY

Although probably more accurately defined elsewhere in the seminar it would be useful to the reader to understand in general terms the definition of "best practicable technology". It was the fundamental purpose of the task force to establish the highest degree of control of waters leaving mining operations in Canada that could be achieved by methods that existed in actual practice under Canadian conditions. The effluent criteria established therefore should be attainable by mine operators by applying the best available technology.

TAILINGS DISPOSAL - SELECTING A SITE

It is accepted that one does not have a choice in selecting a mine site. Ore exists where you find it! A choice is available however for siting the concentration and tailings disposal facilities. In the past many concentrators and tailings disposal areas were simply located in the handiest area close to the mine. Often insufficient consideration was given to seepage control, dust abatement, dam stability analysis and ultimate abandonment plans. To minimize costs associated with meeting present day mine/mill effluent criteria, greater care must be exercised in site selection of the surface facilities than in the past. It is seldom a job for a single engineer; proper evaluation of all the variables requires the input of many disciplines in order to optimize the site selection process.

Mill tailings form the largest single waste product from a mine/mill operation and the disposal of these tailings exert a major influence on the design of a mine/mill complex. In addition to tailings solids, three kinds of liquid waste flows must be handled in a mine/mill operation; acid mine waters, tailings water and contaminated surface drainage including tailings pond seepage. The most common means of treating these waste waters is to discharge to the tailings disposal area.

Originally, the sole purpose of a tailings impoundment area was to prevent the discharge of substantial amounts of solids into receiving watercourses. This, of course, is still a primary requirement of a tailings pond but over the past few years the situation has increased along with our knowledge of the damaging effect on aquatic and human life of various soluble constituents present in waste waters. In many instances the tailings pond is now called upon to provide a large degree of chemical treatment to the liquid wastes within the pond. A typical pond may be required to perform the following functions:

- 1) removal by sedimentation of tailings solids
- 2) acid neutralization
- 3) formation of heavy metal precipitates (hydroxides)
- 4) sedimentation of metal precipitates
- 5) perpetual retention of settled tailings and precipitates
- 6) stabilization of oxidizable constituents, e.g. thiosalts to sulphates, flotation reagent residuals
- 7) balancing action for influent quality and quantity fluctuations
- 8) storm water storage and flow balancing

Tailings ponds have been virtually universally accepted as the primary means of treatment due to the ability to effectively perform many of the above listed functions at a relatively low cost.

In opposition to the above noted advantages offered by a tailings impoundment area the following potential disadvantages must be considered.

- 1) The large surface area can contribute high volumes from precipitation to the overall water balance. In cases where recycling of tailings water is practiced this is not necessarily a disadvantage. Precipitation will have a dilution effect on the quality of the reclaim water where high concentrations of certain dissolved materials would be detrimental to the process. The large quantity of precipitation will also reduce raw water requirement.
- 2) The tailings area creates a potentially severe rehabilitation problem if tailings are acid forming.
- 3) The disposal site is often difficult to isolate from natural drainage areas.
- 4) The pond is subject to climatic variations, particularly thermal skimming and seasonal variations in bio-oxidation efficiency.
- 5) Often difficult to ensure good flow distribution.
- 6) Requires careful control of seepage through dams.
- 7) Installation is expensive in many situations due to high cost of retaining structures and need for good engineering design to prevent problems such as liquefaction and piping, followed perhaps by catastrophic failure of the embankment.
- 8) Dust problems are often observed unless surface stabilization is achieved by revegetation or by the use of chemical binders or rock covers.

The site selection will obviously be influenced a great deal by such cardinal factors as the size of the mine/mill operation, the life expectancy of the operation and the physical characteristics of the tailings material. Ideally, feasibility studies will have established this basic information and pilot plant studies will have confirmed the degree of water recycle compatible with acceptable mill recovery efficiency.

The data base necessary for final site selection should also include detailed topographic information, knowledge of soil conditions, rainfall statistics as well as direction and velocity of prevailing winds.

It is the intention of the writer to describe by case study the application of the broad principles noted above in two recently developed tailings disposal/recycle systems. For more general treatment of the subject the reader is referring to several excellent literature sources. (1, 2, 3)

CASE STUDY #1 - SHEBANDOWAN

Shebandowan is a 10,000 ton per week underground nickel mine owned and operated by the International Nickel Company of Canada, Ltd. Located in an important vacation area of Western Ontario, it was brought into production in 1972 after several years of extensive environmental studies and planning.

The site of the Shebandowan mine/mill complex is approximately 60 miles west of Thunder Bay (Figure 1). Shebandowan is located on the Precambrian Shield, midway between INCO's Sudbury and Thompson, Manitoba, operations.

During the 1960's surface exploration programs confirmed the existence of an orebody of commercial significance. During 1966-67, the No. 1 development shaft was completed and underground exploration commenced from the 1000 ft. level. In 1968, the decision to bring the mine into production was announced.

In the years before INCO's intensive development of the orebody, Shebandowan Lake had built a wide reputation as a tourist centre. Over 750 cottages are located along its shores, and swimming, boating and fishing are the summer pastimes of the residents. The residents expressed concern over the development of a mine in the midst of their vacationland.

Based on concern for environmental protection, and to reassure local citizens, INCO initiated an intensive environmental study to define the ecology of the region before the mine operations began. This would help predict any adverse effects and mitigate them before environmental damage could occur.

The orebody lies directly below the lake in Southwest Bay of Shebandowan Lake (Figure 2). The principal ore minerals are pyrrhotite, pentlandite and chalcopyrite.

If the property had been developed according to short-term economic criteria alone, it is quite likely that part of Lower Shebandowan Lake would have been drained to permit mining by open-pit methods. This was not an acceptable alternative because of the value of the area as recreation land and as wilderness.

The aquatic environment was recognized as being of greatest concern. The majority of the programs which were later initiated were

directed towards protection of the water. The river systems of the area are sensitive, with low nutrient status and with little buffering ability. This means that uncontrolled interference with the existing aquatic environment could have wide-ranging consequences and that the recovery from such an interference would, at best, be slow. An extensive water quality monitoring program had to be undertaken well ahead of production.

The objectives of the monitoring program were to determine the characteristics of the aquatic environment in the vicinity of the mining operations and, particularly in the initial stages, to determine the baseline conditions before the mine came into production. Details of the pre-operational monitoring are reported in the literature (4).

Close examination of topographic mapping of the area surrounding the mine site within a radius of several miles revealed only two separate receiving watercourses; the Gold-Creek-Matawin River system (Figure 3) and Lower Shebandowan Lake (Figure 4)

The pre-operational water quality monitoring program concentrated on the examination of these two potential receiving watercourses in order to evaluate their ability to assimilate the eventual waste waters from the mine/mill under development.

Results of a 2 year monitoring program revealed physical and chemical characteristics typical of most oligotrophic northern waters. The waters are soft with very little buffering capacity and low concentrations of plant nutrients. The biological communities also reflect this - both phytoplankton and benthic organism counts were low.

Examination of the area for suitable tailings disposal sites revealed only one ideal site - by definition of an ideal site at this property - a site that could be developed with minimum dam construction, low permeability of the underlying soil and capable of storing the entire tailings discharge over the expected 15-20 year life of the operation. Such a site was identified some 10,000 feet due east of the mill site and located in a 300 acre basin forming the headwaters of Gold Creek.

It was anticipated that the discharge of high-sulphate tailings effluent into Gold Creek would change the existing soft water environment into a moderately hard water environment in at least the upper reaches of the creek.

Concurrent with pre-operational monitoring, pilot plant work on Shebandowan ore samples shipped to Copper Cliff revealed that mill recovery efficiency could be maintained when operating in closed-circuit with the tailings pond. The studies also indicated that due to the ultra-basic host rock acid generating potential of the tailings was low and low pH/high sulphate levels should not be expected.

Based on the results of a multi-discipline study program of processing studies; hydrologic and meteorological investigation, biologists and soils scientists, the following mining and milling operation was developed.

- 1) The ore underlying Lake Shebandowan is hoisted up No. 2 Shaft then conveyed one half mile back from the lakeshore to remove the concentrator out of site from the lake (Figure 5).
- 2) Underground mine water including in-leakage from the lake is pumped to surface and on to the tailings disposal area. As the concentration operation is in closed-circuit with the tailings area, the mine water and the relatively small flow of sanitary wastes are the only waters reporting in open circuit to the tailings pond (Figure 6).
- 3) To improve mine water quality a water treatment plant is located below the 2000 foot level at #2 Shaft to remove all settleable solids prior to discharge to the tailings area. The treatment flowsheet consists of a 100' long x 16' wide clarifier (Figure 7) with the collected sludge reporting to a vacuum filter station discharging filter cake onto an ore conveyor. Details of the INCO-developed underground clarification/filtration system have been described elsewhere (5).
- 4) The 300 acre tailings pond was designed to be sufficient for the expected life of the operation. The coarse tailings are used as backfill underground. Only the fine tailings are discharged in the disposal area for sedimentation and recycle.

One major drawback to the settlement of fine tailings in tailings ponds is wave action created by even light winds. The Shebandowan tailings pond was originally a peat filled depression with a cover of pine and spruce. The trees were left to stand inside the impoundment dams (Figure 8). The trees reduce wave action and assist in suspended solids removal. Suspended solids in the overflow or recycle system has normally been between 1 and 5 ppm.

The monitoring program initiated in the pre-operational phase has continued following start-up of operations in 1973. No significant change in the physical, chemical or biological parameters have been detected to date. The mine appears to have had a negligible effect on the ecology of the receiving watercourse.

CASE STUDY #2 - COPPER CLIFF "R" AREA

In the late 1960's it was recognized that the existing tailings disposal sites in the Copper Cliff area would be filled to completion by the mid 1970's. In addition, water quality studies indicated that tailings overflow and seepage effluents did not meet the existing water quality criteria prevailing in the province. Following major studies by a consulting firm and an in-house task force, a new 2500 acre tailings impoundment area, seepage collection stations and two tailing effluent treatment plants were approved for development. This will provide tailing disposal facilities on past the year 2000 and provide a final effluent capable of meeting present and predictable effluent quality for years to come.

Commencing in 1930 a small area north of the Copper Cliff Mill was developed to receive tailing slurries (upper pond). As milling rates increased, additional tailings impoundment areas were developed west of Copper Cliff (Figure 9). To date some 2500 acres of impoundment area has been developed and much of the area has been filled to capacity. Presently only the "P" and "Q" areas remain available for receipt of tailings and other waste solids and liquids. Tailings from the Creighton (now inactive) Copper Cliff, Frood Stobie and Clarabelle Mills, mine waters from Creighton, Copper Cliff North and South, Frood and Stobie mines and process effluents from the Iron Ore Recovery Plant all discharge to the P-Q tailings area. Loadings are approximately 30,000 TPD solids in some 30 million gallons per day of waste water flow.

The objective of the design team combination of James F. MacLaren Ltd. and INCO technical staff was to establish a long term deposit area providing minimum hazard to the environment. Examination of the general Copper Cliff area shown in Figure 9 demonstrates constraints not normally encountered in a tailing area siting study - the area can be described as in a mature state of development with long established residential areas to the east and west and important bodies of water to the north and south. In addition land ownership had long since transferred from the Crown to private ownership and without the powers of expropriation INCO studies were basically confined to large blocks of land held by the company.

Adjacent to the west of the existing tailings area a 700 acre lake was centered in a 2500 acre watershed (Figure 10). Through a series of site eliminations the Meatbird area was selected as being the only feasible site capable of providing long term storage capability for the Copper Cliff area mining, milling operations.

Due to the proximity of the residential areas of Lively and Creighton, great care was taken in the design of the tailings dams. As shown in Figures 11A and 11B an upstream method of berm design was chosen with outside slopes designed to accommodate agricultural equipment required to establish and maintain the vegetation necessary for dust control. The use of

well drained starter dams necessitate a series of seepage collection stations with pumps capable of returning seepage water back over the berm and into the tailings pond.

In spite of improvements that will result from the large pool provided by the new area it was established by laboratory work that downstream treatment could be required to meet the predicted receiving stream water quality criteria of the province. Pilot plant studies of the existing effluent in Copper Cliff Creek (the receiving stream) indicated that lime treatment assisted by a high-molecular weight polymer and employing a massive sludge recirculation clarifier (Eimco Reactor-Clarifier) a low turbidity and low contained metal value water could be produced under all seasonal conditions.

Figure 12 and Figure 13 illustrate the two clarification treatment plants now under construction on Copper Cliff and Nolin Creeks. The Copper Cliff Creek plant has a capacity of 60 MGD and consists of 2-135 foot diameter reactor clarifiers. The Nolin Creek plant has a capacity of 7 MGD and consists of 1-80 foot diameter clarifier of the same design.

Costs of the total development work have been estimated at 25 million dollars and upon completion of the project the INCO Sudbury operations will be served by storage and treatment facilities that should satisfy our requirements well into the next century.

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4. Ferguson, W. C. et al - "Water Quality Monitoring at the Site of a Proposed Base Metal Mining Complex" 74th annual meeting of the C.I.M., Ottawa, April, 1972.
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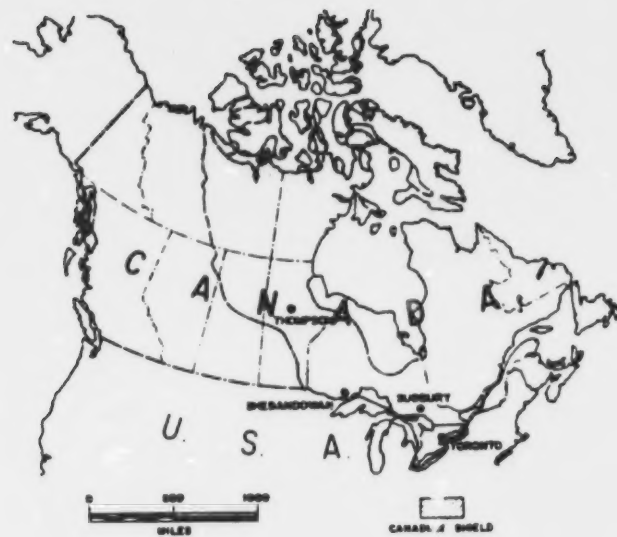


FIGURE 1 - LOCATION MAP

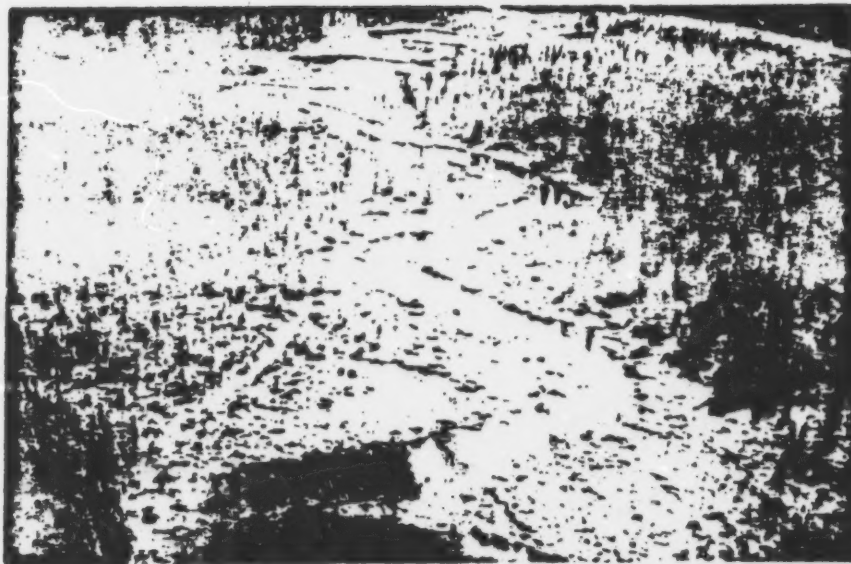


FIGURE 3 - GOLD CREEK



FIGURE 4 - SHEBANDOWAN LAKE
DISCHARGE INTO
SHEBANDOWAN RIVER

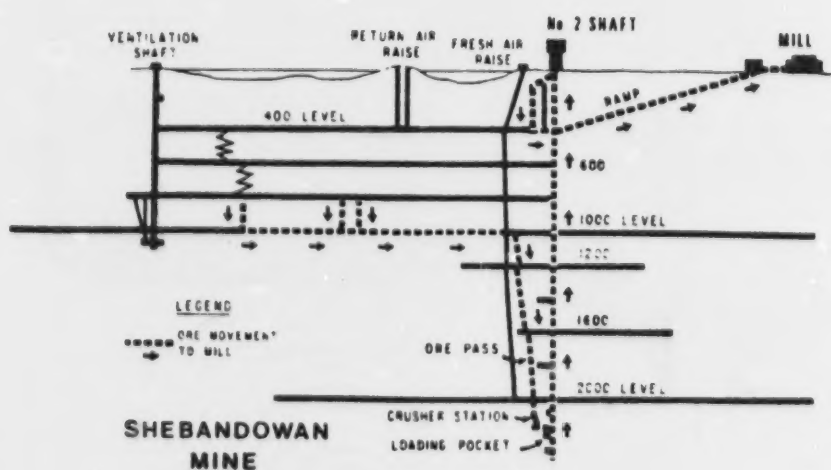
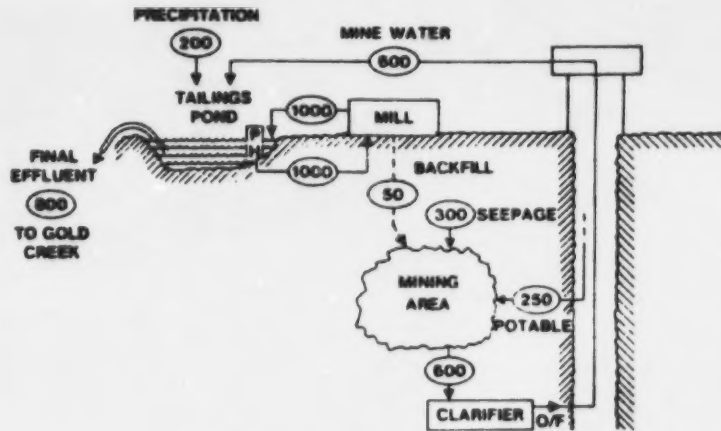


FIGURE 5 - SHEBANDOWAN MINE
LAYOUT

SHEBANDOWAN MINE/MILL WATER FLOW SCHEMATIC



Note: All figures displayed represent Imperial Gallons per Minute

FIGURE 6 - SHEBANDOWAN WATER
BALANCE

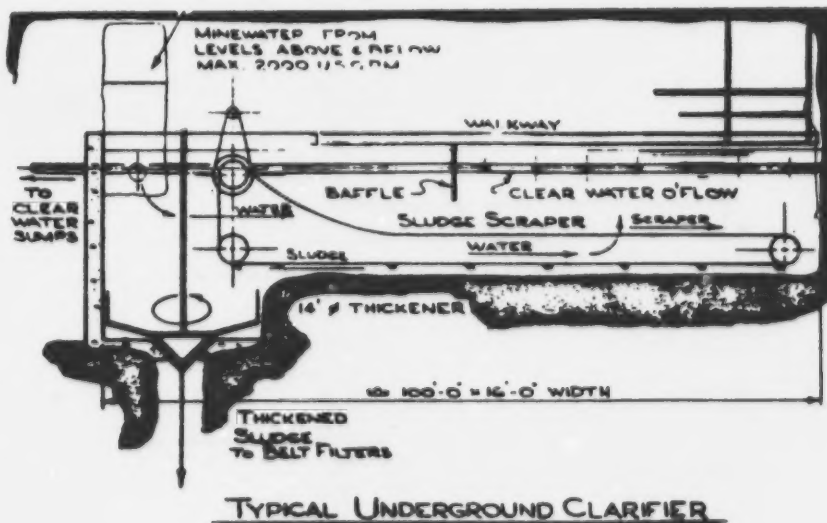


FIGURE 7 - UNDERGROUND CLARIFIER

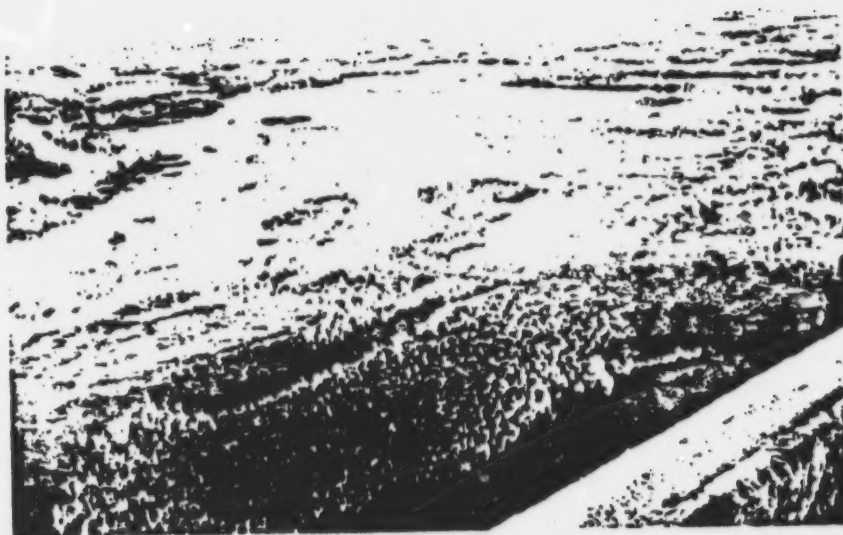


FIGURE 8 - SHEBANDOWAN TAILINGS
AREA

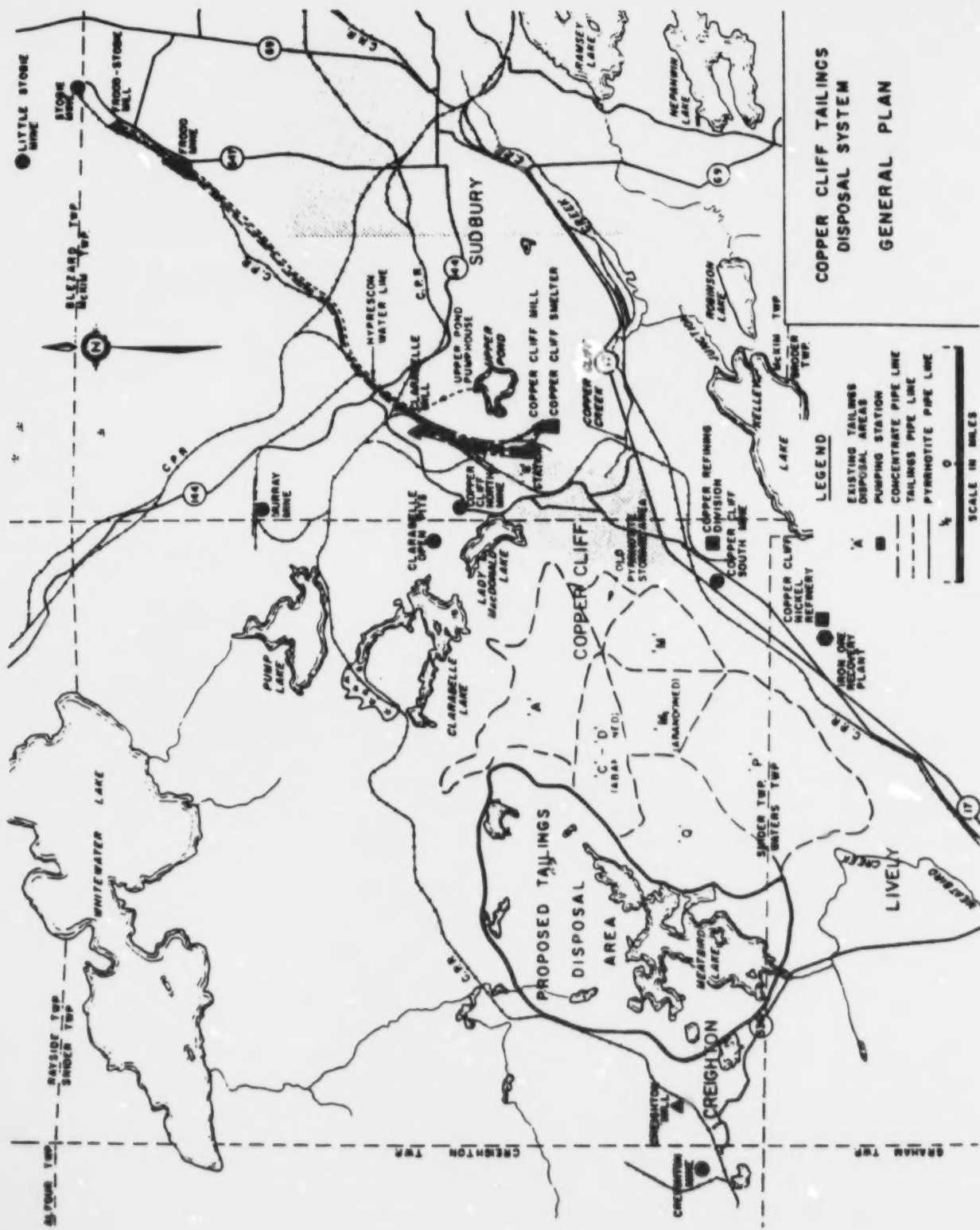


FIGURE 9 - COPPER CLIFF TAILINGS
DISPOSAL SYSTEM
GENERAL PLAN

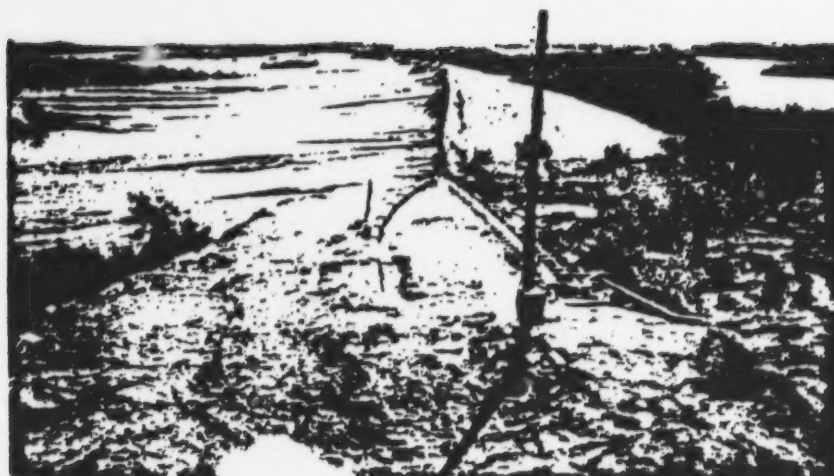


FIGURE 10 - LOOKING SOUTH-WEST FROM Q
AREA TO NEW MEATBIRD AREA

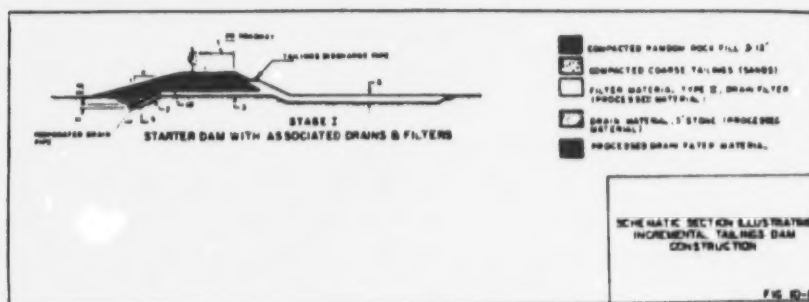


FIGURE 11A - TAILINGS DAM DEVELOPMENT

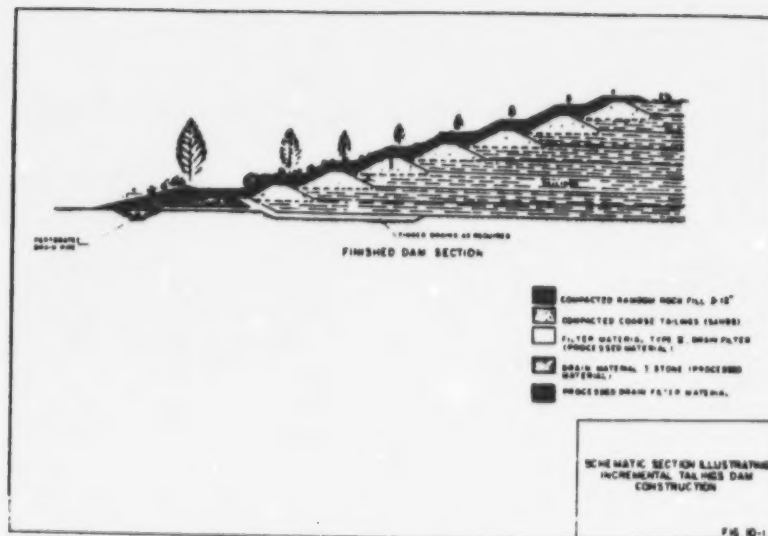


FIGURE 11B - TAILINGS DAM DEVELOPMENT

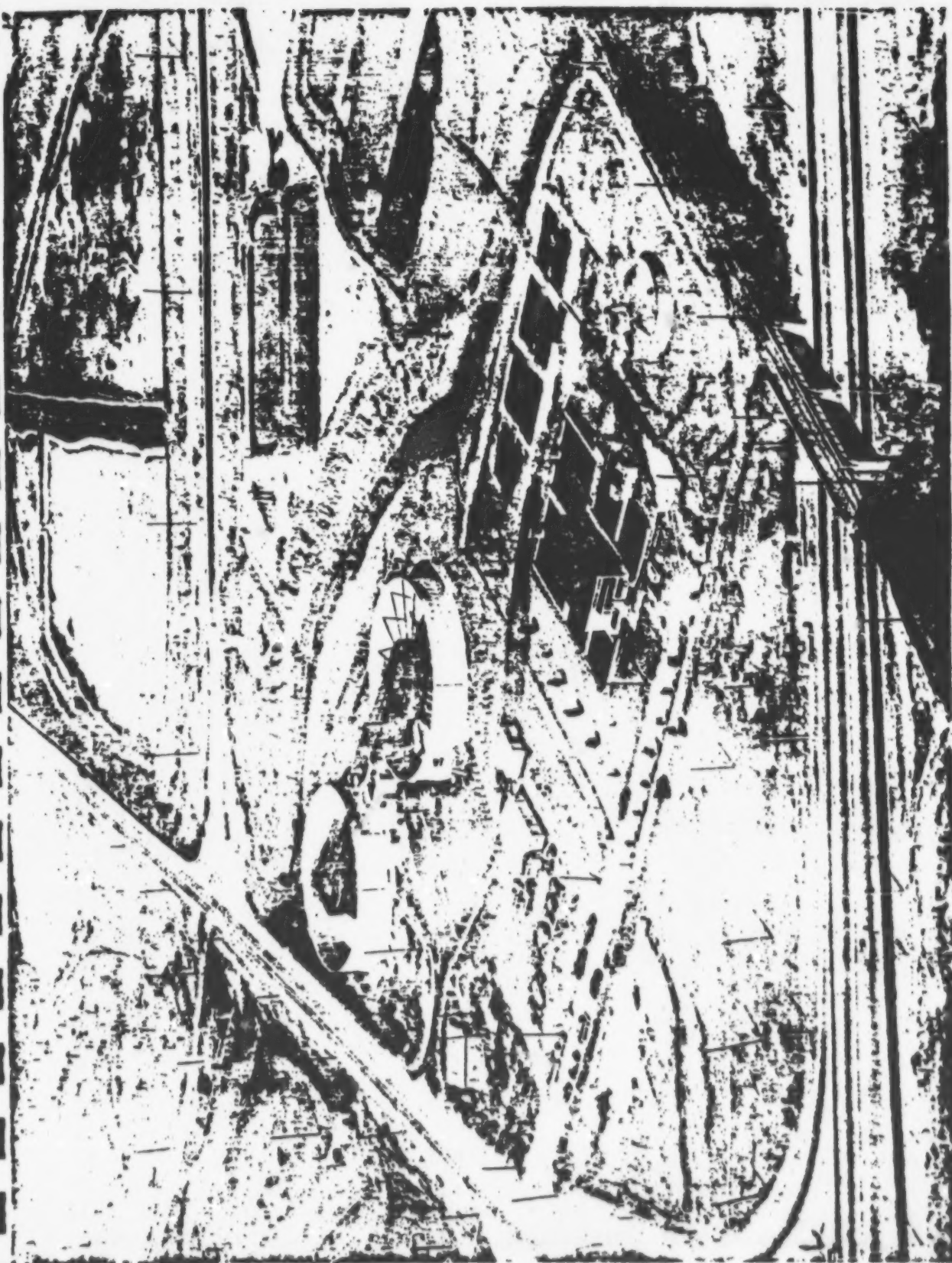


FIGURE 12 - COPPER CLIFF CREEK
TREATMENT PLANT

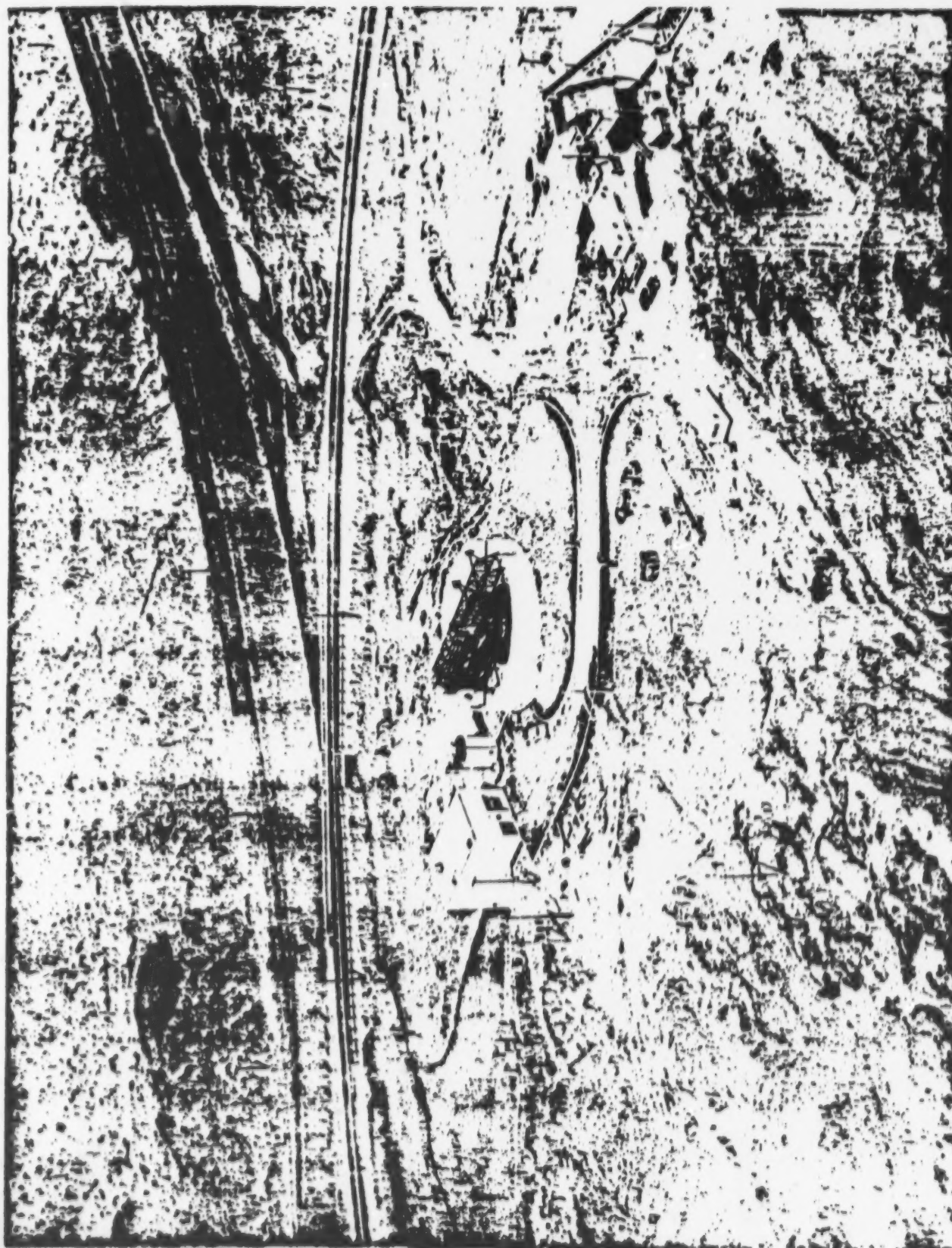


FIGURE 13 - NOLIN CREEK TREATMENT

11

TAILINGS DISPOSAL AT INCO IN COPPER CLIFF

LOCATION

The Ontario operations of Inco Ltd. are principally located in the Sudbury Nickel Basin. Two mining companies, Inco Ltd. and Falconbridge Nickel Mines Ltd., operate within the Sudbury basin and extract nickel, copper, iron, cobalt, gold, silver, precious metals, selenium and tellurium.

HISTORY

The presence of copper and nickel in the Sudbury Region was known as early as 1856 and rediscovered in 1883 during the construction of the Canadian Pacific Railway.

The first mine, Copper Cliff No. 1 was started in 1886 by the Canadian Copper Company to mine copper ore. The International Nickel Company was formed in 1902. Mining in the area steadily increased and by 1915 the annual production was more than 1,300,000 tons of ore. Most of the important orebodies in the basin were discovered from surface outcrops. The first orebody discovered by diamond drilling through glacial sands and gravel was in 1916; from which evolved in 1930 the Falconbridge Mine of Falconbridge Nickel Mines Ltd.

Some 20 mines are now located along the periphery of a roughly oval ring with axis of 37 and 17 miles covering the periphery of the orebody.

GENERAL LAYOUT

Inco Ltd. has developed some 15 mines (operating + standby). The ore is mined by caving and backfill stoping methods.

The ore is crushed to minus 8" and transported by rail to Clarabelle Mill and by conveyor to Frood Stobie Mill (respectively 35000 and 24000 T.P.D.). Both mills produce a bulk copper-nickel flotation concentrate and a tailing. In addition the Clarabelle Mill produces a magnetic and flotation pyrrhotite concentrate. The bulk of the pyrrhotite at Frood Stobie Mill is rejected to tailings. The bulk copper-nickel concentrate of both primary mills is separated into a copper and a nickel concentrate at the Copper Cliff Mill. The concentrates are processed in the copper smelter (flash furnace) and the copper refinery, the nickel smelter (reverberatory furnaces), matte processing and the nickel refinery. Precious metals, gold, silver, cobalt, tellurium and selenium are recovered as byproducts from refining operations.

The Clarabelle Mill pyrrhotite concentrate is reground and upgraded in the Copper Cliff Mill and further processed to magnetite and sulphuric acid at the Iron Ore Recovery Plant.

The combined tailings from the three mills are pumped to the tailings area. The tailings decant water is recycled as process water in the three mills. The three mills do not use fresh water.

The coarse fraction of the tailings is mixed with cement and returned underground as backfill.

ORE COMPOSITION

The nickel intrusive is associated with norites, quartz diorites, granite breccia, contact breccia.

The ore is made up of disseminations, narrow and massive stringers and lenses of massive sulfide.

The principal sulfide minerals are pyrrhotite, pentlandite and chalcopyrite. The proportions of the sulfide minerals vary from one orebody to another, consequently the metal content of the massive sulfide varies, as does the ratio of copper to nickel.

INCO TAILING DISPOSAL SYSTEM

Prior to 1930, the practice of "open heap roasting" was employed for the partial roasting of the iron sulphide fraction of the ore. A typical installation was the O'Donnell Roast Yard located some 11 miles west of the town of Copper Cliff.

Open heap roasting of mine ore was replaced in 1930 with construction of the Copper Cliff Mill and the smelter. The Creighton Mill became operational in 1951, followed by Levack Mill in 1959, Frood-Stobie Mill in 1967 and Clarabelle Mill in 1971. Creighton Mill and Levack Mill are now shutdown.

Over the past 53 years, the tonnage milled has increased manyfold. With the operation changeover from "heap roasting" to milling and smelting came the requirement for disposal areas for the tailings slurries.

Originally at Copper Cliff, an area to the east of the Copper Cliff Mill/Smelter complex was used to receive the tailings. As this area became filled and tailings tonnages increased, new facilities were developed to the north and west of Copper Cliff now identified as "A" area (see Figure 1). As the volume of tailings to be disposed of continued to increase, the demand for larger tailings facilities necessitated the development of some 2300 acres between the towns of Lively and Copper Cliff. Most of this area has now been filled. The areas which have been removed from active operation and had the surface revegetated are "C-D", part of "M" and "Q" areas. The part of "M" area which is still in service, is used in a dual role, i.e. the emergency storage of excess pyrrhotite and the treatment of waste flows from non-milling operations. The part of "Q" area which is still active is, because of the location of existing tailings slurry lines, used as a conveyance for tailings to the "P" area. "P" area is now the only area in active operation for receipt of tailings slurry and is expected to be filled in the next few years.

A new area, "R" area, 2400 acres, is presently being developed. The "R" area is expected to be sufficiently prepared for the receipt of all Inco's tailings by early 1987. The full development of the area will be completed by 1994 and its tailings storage capacity will then be equal to the present known ore reserves of Inco.

TAILINGS PONDS

The primary function of the tailings ponds besides tailings storage, is to serve as separators of solids and liquids and to provide a clear water overflow for reuse in the milling process. The tailings slurries are characterized by:

- a high solids load generally in the order of 25 - 30% solids by weight.
- a fine particle size, not exceeding a topsize of 48 mesh, with 50% by weight finer than 200 mesh.
- a variable pH generally in the alkaline range, since in the final copper-nickel flotation separation process a high pH is maintained for most effective beneficiation.
- generally, a low dissolved metals content. The dissolution of metals is minimized because of operation in the alkaline range.
- a significant content of thiosalts, readily formed because of operation at a pH of more than seven.
- a significant chemical oxygen demand.
- saturation level of various other ions, Cu, Mg, Na, SO₄, etc.

The most notable effect of the various chemical reactions and possibly biological processes in the tailings ponds is a depression in the pH value. This is partly attributed to oxidation of thio-salts and/or hydrolysis of ferrous and ferric iron products.

The depressed value of the pH in the tailings pond in turn enhances the solubility of base metals. The final pH value in the tailings

pond is largely dependent upon temperature and residence time.

As a result of the solids/liquid separation and other reactions occurring in the tailings pond, the decant is usually characterized by:

- a very low solids level, depending upon the size of the settling pond.
- a pH generally in the neutral to acid range.
- some dissolved iron and heavy metals (pH dependent) and some partially oxidized sulphur compounds.
- a chemical oxygen demand depending upon the concentration of thiosalts.

In addition to the mill tailings, several other streams are pumped to the tailings area.

- Mine waters from the mines in the Copper Cliff and the Frood-Stobie complexes. Part of the mine water in the Frood-Stobie complex is directly used in the mill.

Mine water is usually acidic and results from groundwater, seepage, drilling water, dust control procedures and hydraulic backfilling activities.

Mine waters are clarified to remove highly abrasive suspended solids prior to pumping. The mine water treatment process includes reduction of heavy metals concentrations and removal of the settled sludge.

- Iron Ore Plant rejects are pumped to the tailings area (P area). The Iron Ore Plant dead roasts the pyrrhotite produced at the Copper Cliff Mill. The roaster gases are the feedstock for the sulphuric acid plants. The roaster kiln discharge is quenched and is pumped as a slurry to the tailings area.

- Some refinery and smelter waste streams are pumped to the "M" tailings area.
- Seepage waters from percolation of tailings pond water through dams, fissures and cracks in natural rock and pervious soil have a characteristically low pH value and are contained in ponds downstream of the tailings dams to be returned to the tailings settling ponds.
- Storm and spring runoff waters are contained in the settling ponds and released with tailings decant water for re-use in the milling process.

The tailings decant water (either siphons or decant towers) is conveyed through natural drainage courses via a pumpstation to a holding reservoir, (Upper Pond). The Upper Pond is the water supply for the mills.

Decant water and natural runoff in excess of the mills' requirements, along with smelter and refinery effluents is processed in water treatment plants prior to release to natural water courses.

Make-up water and potable water for the Inco operations is pumped from the Vermilion River.

OPERATION OF THE TAILINGS AREA

Tailings slurries are discharged from 20" lines to the tailing pond by spigotting and open end discharge using the upstream method of tailing disposal.

Spigotting implies spaced openings along a section of the perimeter pipeline with short lengths of pipe directing the slurry flow into the tailings pond. Open end discharge implies full discharge of tailings into the pond itself.

The spigots, which are generally spaced at no less than 20 foot centres, are placed near the bottom of the slurry pipeline so that the coarser material is preferentially withdrawn. The present spigot method uses a 4" pinch valve mounted on an 8' length of steel pipe inserted in the line. Depending on the line pressure, the discharge end of the attached polyethylene pipe can be moved up to 150' from the slurry line.

The effect of spigotting is to allow prompt deposit of the coarser fractions along the inside of the tailings pond dams. With the water level in the pond considerably below the elevation of the tailings pipeline, longer tailings beaches with a gentle slope result (typical slopes - see Figure 207). The slimes fraction of the tailings is carried further down the beach towards the water's edge. When the deposited tailings along the spigotted pipeline builds to the crest level of the dam, the spigotting operation is moved to another section of the pond perimeter. The coarse material is bulldozed back to form a new 10' higher crest on the dam, inset 20' from the previous, to give an overall outside slope no steeper than 1 in 4.

The coarse tailings has good drainage characteristics and ensures a low phreatic line in the tailings on the perimeter. The size separation obtained by spigotting is significant. Typical size analyses of a spigot discharge sample and of a sample taken 100' from the spigot discharge, are as follows:

<u>Mesh</u>	<u>At Discharge</u>	<u>100' From Discharge</u>
+100	66	16
+200	17	19
+325	6	35
-325	11	30

Earlier spigot methods used a 1" ID Ni-hard nipple inserted in the line by drilling a hole. The sand was drawn away from the dam by a rubber hose. This method required a great deal of attention to keep it operating properly. The present method using 4" pinch valves and 4" piping requires very few spigots (no more than 6) and is essentially attention free.

The spigotting method for perimeter dam building is usually limited to 8 months/year. The dam building program is organized such that the tailings slurries can be deposited by open end discharge during the winter months.

TAILINGS AREA TERRAIN

The "R" tailings area (figure 1.1) comprises generally irregular terrain, with exposed or very thinly covered rock. Depressions between the exposed rock are occupied by lakes and swamps (up to 60' in depth). The vegetation cover is dense, particularly on the northern perimeter. Natural drainage is in general from north to west and north to south.

The northern perimeter is a high ridge at an average elevation of 1040' geodata with minor valleys. The southern and western perimeter is low land (990' elevation), intersected by deep valleys. East-West and North-South ridges at elevations 1020' to 1000' divide the tailings area in natural subdivisions. The natural topography permits a staged development of the tailings area.

Approximately 60% of the perimeter is bedrock with minor overburden. 25% of the perimeter is soft dry ground underlain by competent glacial drift formations and bedrock. Soft ground, consisting of saturated muskeg and soft clays represents 15% of the perimeter and is encountered at the Western and Southern perimeter in valleys.

Natural watercourses in the active tailing areas are dammed. The water reports to the tailings settling ponds by either gravity flow or by being pumped. Once the development of the 2400 acres expansion is completed, all surface water will report by gravity flow to the settling pond in "P" area.

PERIMETER DAMS

The tailings impoundment areas constructed in the past have been designed primarily to contain the solids fraction of the slurry. Starter dams were constructed of borrow material such as: on site material, mine rock, slag or coarse tailings. The starter dams were incrementally raised using the coarse fraction of the tailings recovered from beaches inside the impoundment. As such, dams were reasonably watertight with the emphasis being placed on stability. With time however, the seepage flows through or under the starter dams were retarded by the slimes fraction of the tailings slurries, resulting in movement of the phreatic line in the tailings dams. Uncontrolled seepage sometimes occurred particularly at the interface of bed rock and tailings. Remedial measures to re-establish seepage control in existing dams were found to be expensive, particularly on the P-area perimeter dams.

In general, our present practice of starter dam construction and incremental lifting of the dams with coarse tailings remains the same. However, more emphasis is placed on incorporating permanent seepage control during the initial phases of starter dam construction.

Starter dams are now constructed of coarse mine rock. The foundation of the starter dams, down to bedrock or competent soil, is prepared by excavation of loose or nonstable materials where necessary (Figures 210, 211, 212, 213).

Since tailings pipelines are carried on top of the starter dams, during the initial stages of tailings disposal, a minimum crest width of 20' is used.

Starter dams at low points are constructed to a crest elevation of 10' above the natural highwater level. The crests of remaining

starter dams around the perimeter are at higher elevations, a minimum of 10' above the original ground level; except in areas of high ground sloping into the area.

The width at the top of the starter dams is related to the crest elevation, which in turn is dictated by the terrain. The crest width, at low points, based on rock with a 35 degree angle of repose, can be as wide as 94 feet. In the deepest valleys the width at the base of the starter dams can amount to 200 feet.

The starter dams are designed to maintain the line of saturation sufficiently below the outside slope to ensure stability during raising, and long term stability when the tailings dams are at their finished heights.

Drainage is achieved by using a continuous blanket of minus 3 inch crushed and screened mine rock on the inside face and the crest of the starter dams. Finger drains, constructed of the same minus 3 inch material, connect into the blanket and extend into the tailings. The finger drains, spaced at 75 foot intervals around the perimeter, are constructed, where practical, at the elevation of the base of the starter dams. The finger drains length is a function of the planned height of the tailings deposit and are up to 120 feet in length. They slope upwards to compensate for settling and may follow the existing ground contours.

A layer of coarse tailings is placed over the blanket and finger drains to act as a sub-drain to seal them and to prevent blinding.

The combination of the drainage blanket, the finger drains and the layer of coarse tailings ensures continuous drainage in the direction of the toe of the dam and furthermore ensures that the phreatic line in the tailings does not surface above the crest of the starter dams.

Drainage ditches are provided around the outside perimeter to intercept seepage. Seepage is collected at several low points

behind impermeable seepage dams and pumped into the tailings area or flows by gravity to the Water Treatment Plants.

Seepage flow is 120 USGPM per mile dam with tailings discharge near the dams and 22 USGPM per mile dam with discharge remote from the dams.

The freeboard of perimeter dams, seepage dams, overflow structures, spillways and settling ponds is based on a maximum storm of 7-1/2 inches rain per 24 hours.

TAILINGS PUMPING SYSTEMS

Prior to 1967, the two mills that produced tailings were Creighton Mill (11000 tons per day) and Copper Cliff Mill (30000 tons per day). Creighton Mill pumped tailings to the western side of the "P" and "Q" areas and Copper Cliff Mill pumped a thickened tailing to the eastern side of the "P" and "Q" areas. Both mills also produced sand for underground mine backfill.

In 1967, when the Frood Stobie Mill (design rate is 24000 tons per day) came on line, a central tailings handling system was installed. A new pump station adjacent to Copper Cliff Mill (B-Station) was built to receive all the tailings from present and future mills, except Creighton Mill. Clarabelle Mill (design rate is 35000 tons per day) was connected to this system in 1972.

B-Station is equipped to classify tailings to segregate the coarse tailings fraction for perimeter dam construction and underground sandfill requirements. B-Station is connected by four 20 inch lines to Mill Station at the tailings area (12000 feet distant).

Also in 1967, provisions were made to re-circulate water to the mills for process purposes. The tailings decant water was intercepted at Copper Cliff and pumped to a reservoir (Upper Pond) adjacent to Copper Cliff Mill. Each mill draws its process water from the Upper Pond.

The present tailings handling system main components are:

- Clarabelle Mill to B-Station, four 12"x14" pumps, 20" lines, 4400 feet distant.
- Frood Stobie to B-Station, two sets of five 12"x14" pumps, 20" lines, 24000 feet distant.

- B-Station to Hill Station, sixteen 12"x14" pumps, four 20" lines, 12000 feet distant.
- Hill Station to "P" - "Q" areas and Creighton Mill, seven 12"x14" pumps, five 20" lines, 10000' to 15000' distant.
- Creighton Mill and intermediate pumping stations, six 12"x14" pumps, two 20" lines, 15000' distant.

When the new tailing area is phased into the system, beginning in 1985, an additional ten 12"x14" pumps and 125000 feet of 20" piping will be added to the system.

The main criteria for Inco's tailings handling system are:

Slurry Transmission Lines:

- 20" polyethylene, 100 psi
- 20" steel, 3/8" wall for higher pressures
- Station piping rubberlined

Line Velocity:

- 6 f.p.s. to minimize pipe wear and to obtain sufficient bedding in the pipe to assist the spigotting operation.

Pumps

- 12"x14" centrifugal, all metal and rubberlined
- V-belt drive, 450 HP, side by side mounted for ease of maintenance
- One variable speed pump per line, controlled from magnetic flow meters and sump level indication

Decant

- Either 42" syphons or adjustable weir decant towers
- Gravity flow to central settling pond

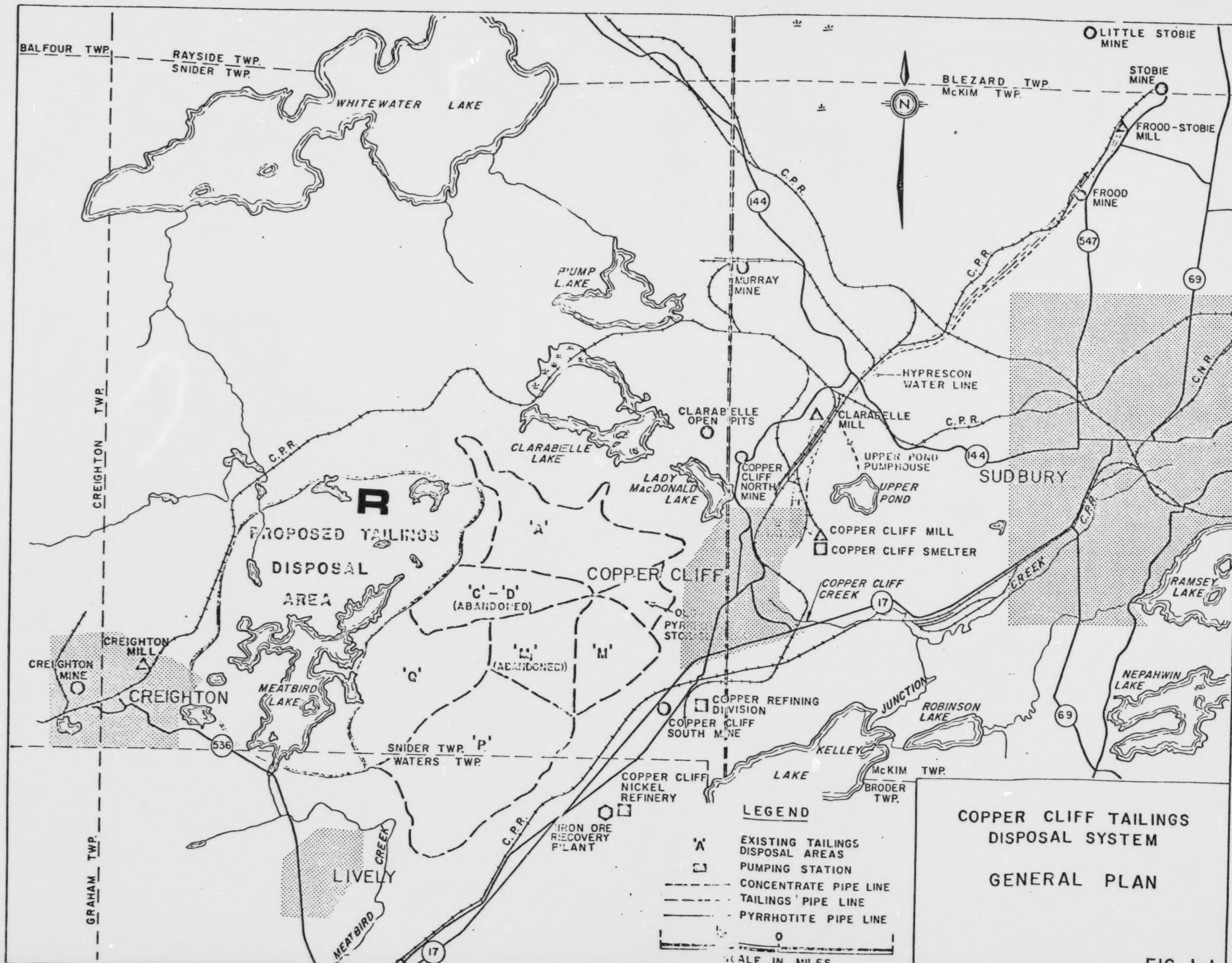
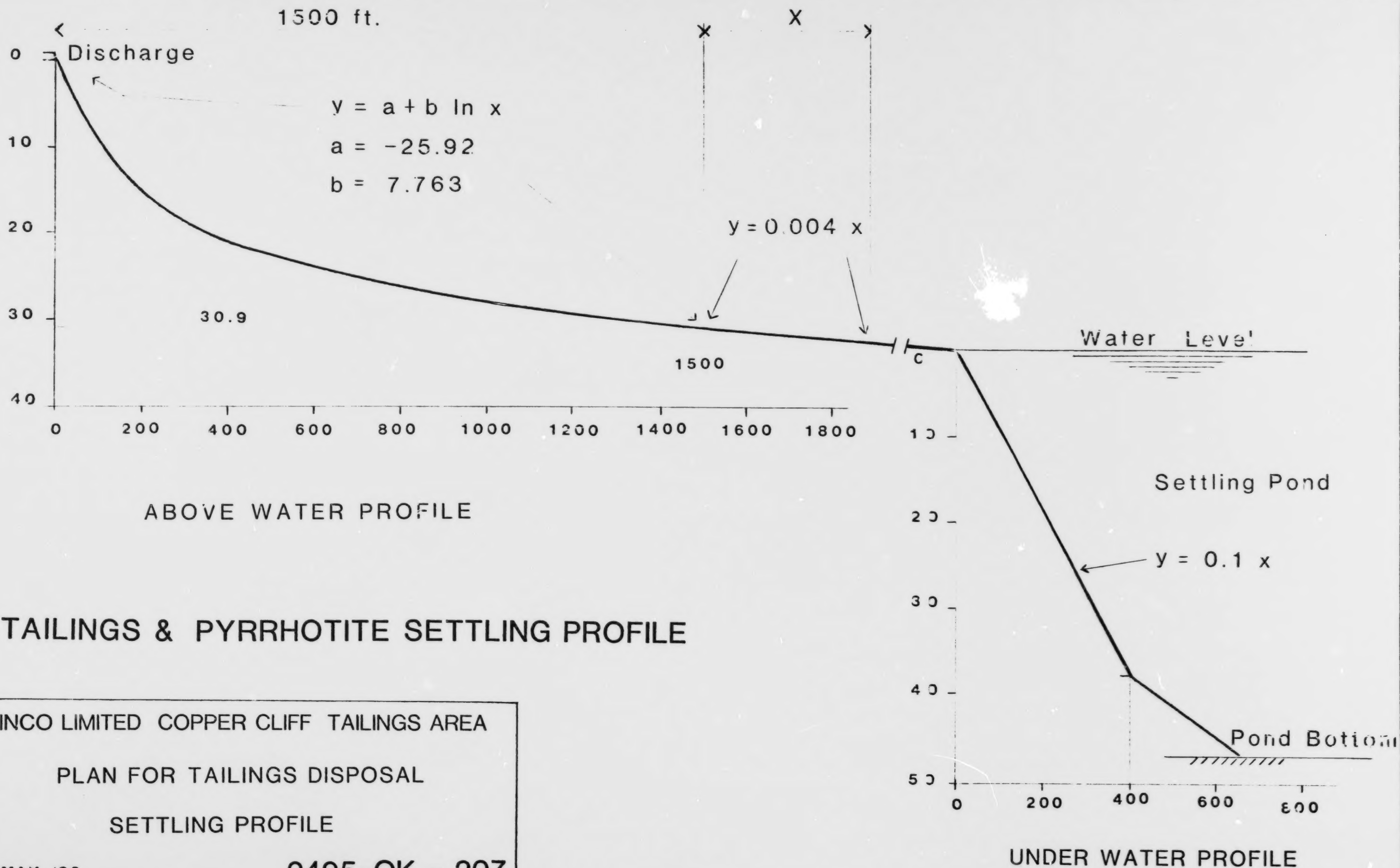
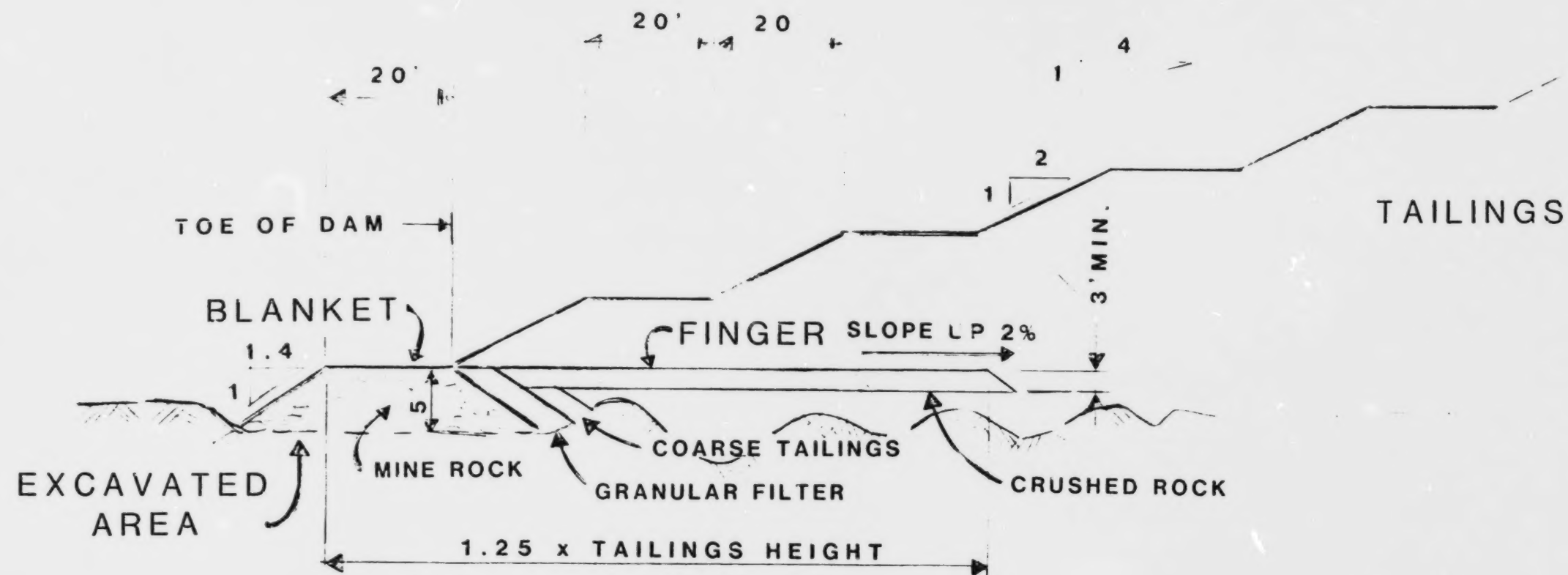


FIG 1-1





STARTER DAM ON HARD GROUND OR BEDROCK TYPE A

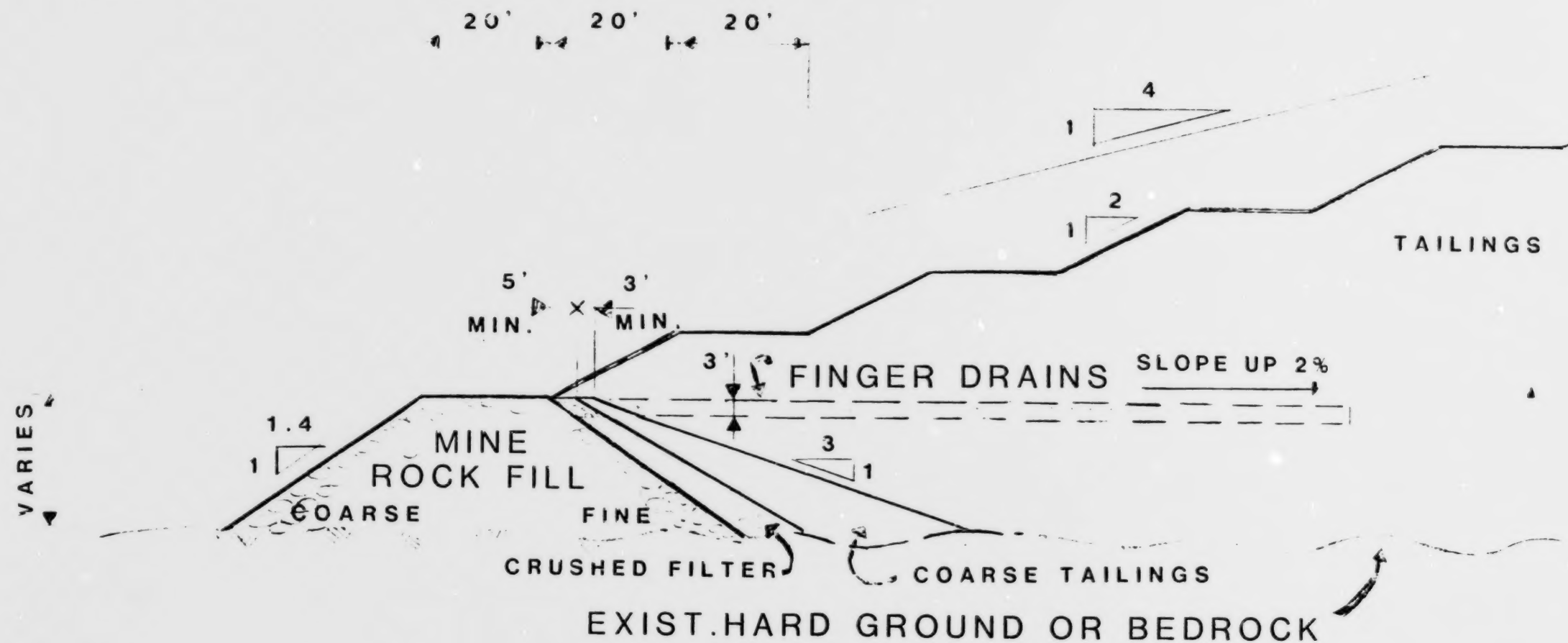
INCO LIMITED
ONTARIO DIVISION, CANADA

COPPER CLIFF TAILINGS AREA
PLAN FOR TAILINGS DISPOSAL
STARTER DAM ON HARD GROUND OR BEDROCK
ON A FLAT SURFACE
SCALE _____ DRAWN BY _____ DATE _____

JOB
EST. NO.

0495-OK - 210

REV.



STARTER DAM ON HARD GROUND OR BEDROCK IN VALLEYS TYPE B

INCO LIMITED

ONTARIO DIVISION, CANADA

COPPER CLIFF TAILINGS AREA

PLAN FOR TAILINGS DISPOSAL

STARTER DAM ON HARD GROUND OR BEDROCK IN VALLEYS

SCALE _____ DRAWN BY _____ DATE _____

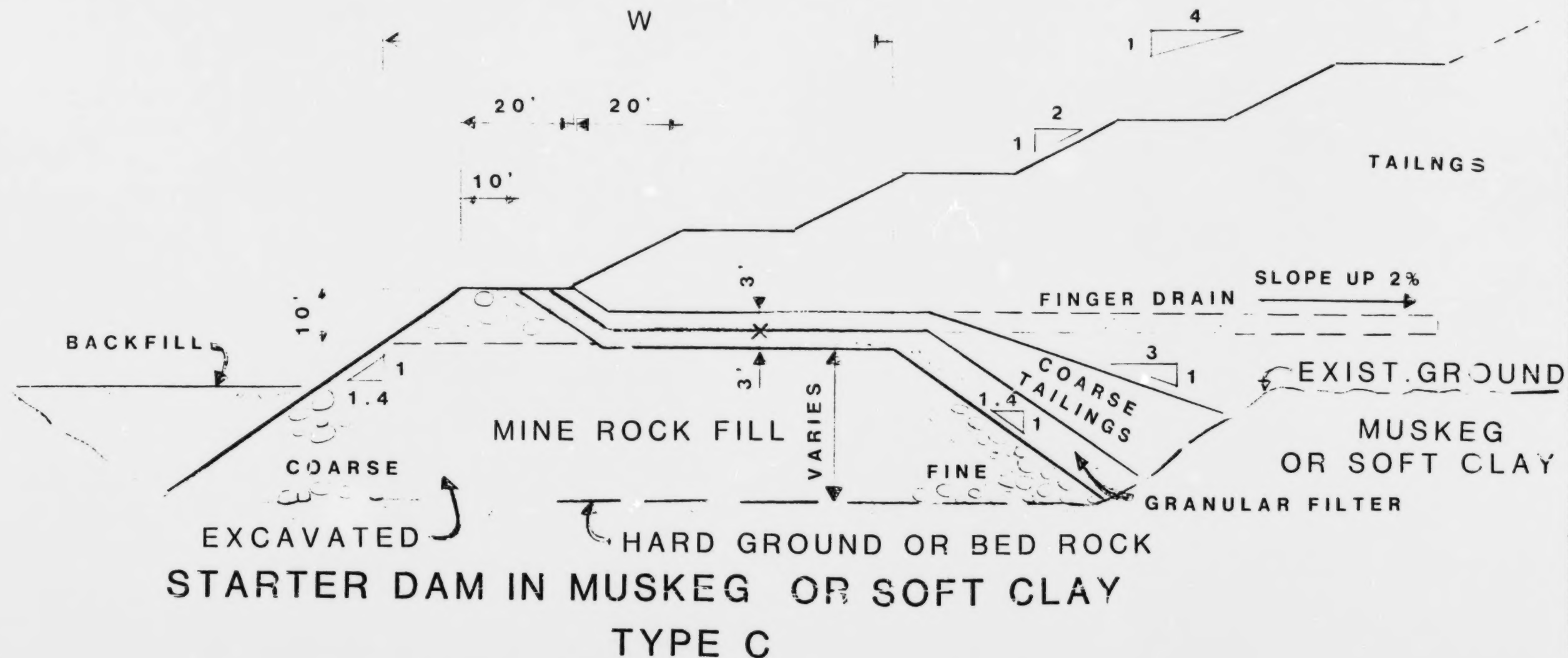
JOB
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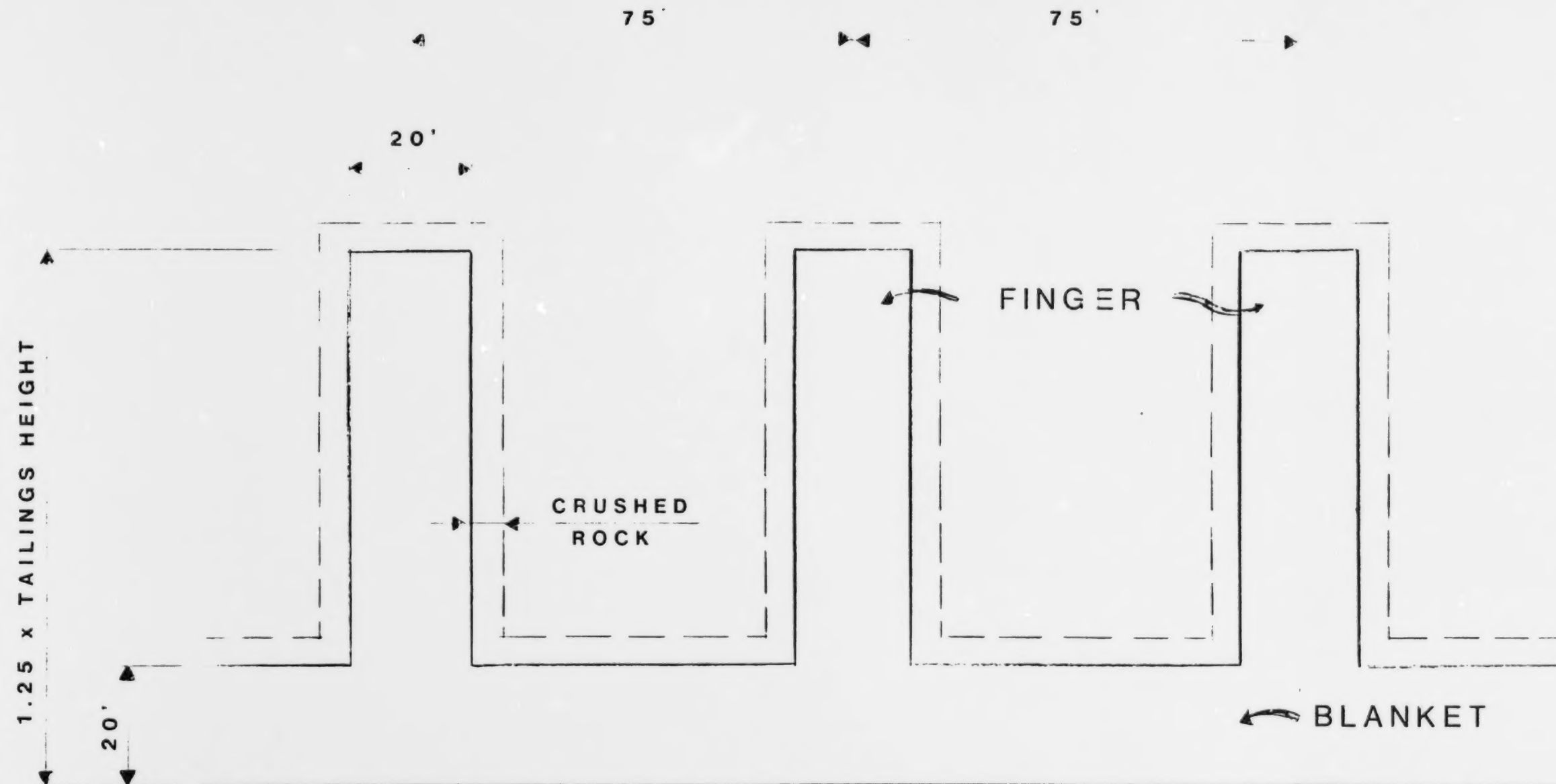
REV.

LEGEND:

MINIMUM WIDTH "W"	- 136'	AT ELEVATION	965'
	122'	"	970'
	108'	"	975'
	94'	"	980'
	80'	"	985'



INCO LIMITED ONTARIO DIVISION, CANADA	COPPER CLIFF	TAILINGS AREA	JOB NO.	0495-OK - 212	REV.
	PLAN FOR TAILINGS DISPOSAL		EST.		
	STARTER DAM IN MUSKEG OR SOFT CLAY				
	SCALE _____ DRAWN BY _____ DATE _____				



PLAN OF BLANKET AND FINGER DRAINAGE

INCO LIMITED ONTARIO DIVISION, CANADA	COPPER CLIFF TAILINGS AREA	JOB EST. NO.	0495-OK - 213	REV.
	PLAN FOR TAILINGS DISPOSAL			
	PLAN OF BLANKET & FINGER DRAINAGE			
	SCALE _____	DRAWN BY _____	DATE _____	

12

APPENDIX C
SHEBANDOWAN CASE HISTORY

SUMMARY

The Shebandowan mine and concentrator, with a capacity of 10,000 tons per week, was opened in 1972 after several years of environmental study and planning. The mine is located in a popular vacation cottage area about 60 miles (96 km) west of Thunder Bay, Ontario. Undertaken before environmental assessment procedures had become an established requirement, Shebandowan is one of the first Canadian examples of effectively integrating environmental work into overall mine planning. Although it is an underground mine, many of the environmental considerations are common to open pit operations and hence it provides a case history for the use of all mine planners.

Early attention was focused on establishing baseline conditions in a two-year water qual-

ity monitoring program. Since production began, water quality monitoring has shown that mining has not caused any significant changes. However, mine drainage disposal arrangements had to be modified in the light of operating experience.

There is no townsite associated with the mine and workers commute from established municipalities. Harmonious relations have been achieved with local cottage residents after their initial fears were dispelled.

Plans are ready to begin revegetating the tailings when a sufficient area of dry elevated tailings has been accumulated. Rehabilitation of the land disturbed during development was begun before start-up and was completed during initial operations.

INTRODUCTION

The Region

1. Shebandowan is one of the first examples in Canada of integrating environmental planning into mine design. Although it is an underground mine (2,500 tons/day), many of the environmental considerations are common to open pit operation. For these reasons, it provides a case history that is useful for all mine planners.

2. Shebandowan is an Indian word meaning "a summer place" (referring probably to the value of the lake to its earliest inhabitants). It is situated in heavily glaciated terrain where depressed areas hold wetlands, muskegs and lakes.

3. The forests are composed of black and white Spruce, with Aspens and Birch on the deeper till soils. Jack Pine is present in the more sandy soil areas. Forest fires together with logging and some marginal farming have disturbed the natural ecology of the region. Figure C-1 shows vegetation typical of the region.

4. The composition of the forest changes with soil conditions. The soil is poor in nutrients (weakly to strongly podsolized). The surface water draining off these soils is consequently low in nutrients. This means that the lakes have little capacity to resist change in pH and hence

are vulnerable to pollution.

5. The site is in Northern Ontario as shown in Fig C-2. This case history illustrates how investigations were tailored to the requirements of the project, to the site and to the regulations then in force. The precautions taken and the effects on design would be similar for an open pit mine. Publication of the history is made possible through the cooperation of INCO Ltd.

Mine Development

6. Historically, the first white man to see Shebandowan Lake was the explorer Jacques de Noyon in 1717. Over 10,000 settlers passed by this area going west. The first steampowered vessel to navigate the northwestern Ontario waters entered Shebandowan Lake in 1871.

7. In 1913, the Cross brothers discovered traces of nickel near the western tip of Lower Shebandowan Lake. The claims held by Jules Cross were purchased by INCO in 1936. Surface exploration programs were intensified in the 1960's, and an orebody of commercial significance was confirmed. During 1966-67, the No. 1 development shaft was completed and underground exploration commenced from the 1,000 level. The decision to



Fig C-1 - Vegetation in the Shebandowan region

bring the mine into production was announced in 1968.

8. The orebody lies directly below the lake in Southwest Bay and strikes in an easterly direction from Discovery Point to the opposite shore (Fig C-3). It extends almost vertically to a depth of 2,000 ft (610 m) and averages 25 ft (7.6 m) in width. It is approximately a mile (1600 m) long. The orebody is contained within a sequence of volcanic rocks and occurs as stringers or veins of sulphides. The principal ore minerals are pyrrhotite, pentlandite and chalcopyrite in peridotite host rock. The ore contains about three parts nickel to two parts copper. Other metals include small amounts of cobalt, silver, gold and the platinum group.

9. The ore movement in the Shebandowan mine is shown in Fig C-4. Ore is passed from the mined area down to the 1,000 level and trammed about one half mile (800 m) to the main ore pass at No. 2

shaft. It drops to the 2,080 level and is crushed in a 36 x 48 in. (0.91 x 1.22 m) jaw crusher. The crushed ore then drops to the 2,160 level to be hoisted to a 4,000 ton (3630 tonnes) underground storage bin above the 400 level. From the storage bin, it moves by conveyor along an inclined ramp to the mill, located a half mile (800 m) inland from the No. 2 shaft. Ore is mined at 2,500 tons (2270 tonnes) per day, four days a week for a weekly output of 10,000 tons (9070 tonnes). The main conveyor is capable of handling 650 tons (590 t) per hour. The No. 1 shaft, which served as the exploration shaft, now acts only as a return airway. An additional return air raise is located on a small island in the centre of Southwest Bay. The main fresh air raise is located near the No. 2 shaft.

10. At the mill, after grinding the ore is fed to a bank of 72 flotation cells - 24 roughers, 24 primary scavengers and 24 secondary scavengers.

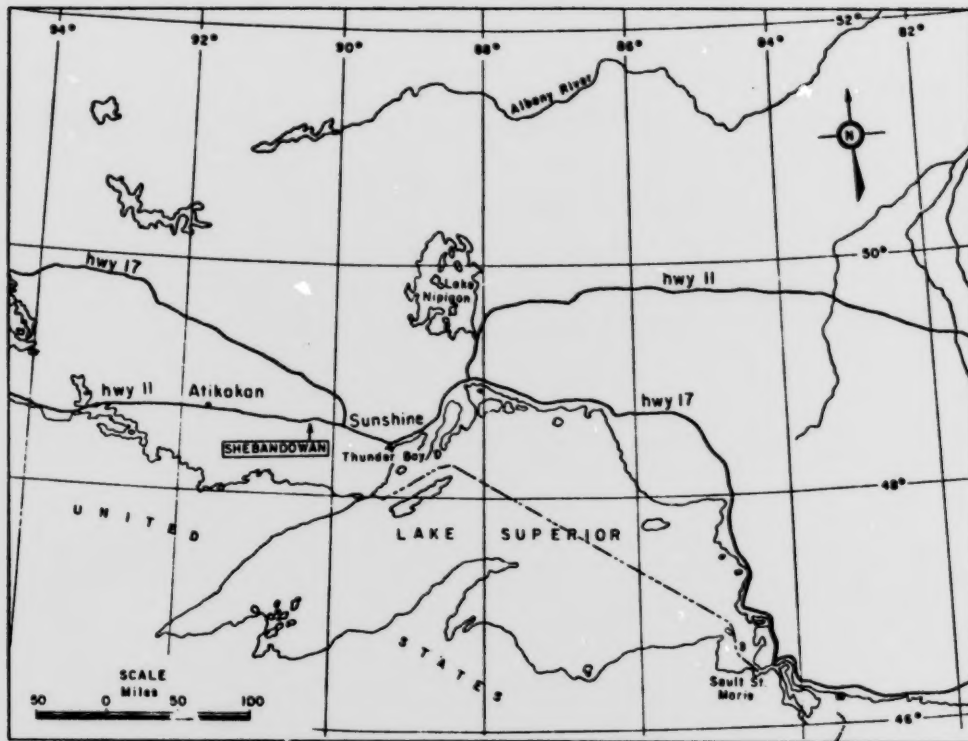


Fig C-2 - Shebandowan mine location

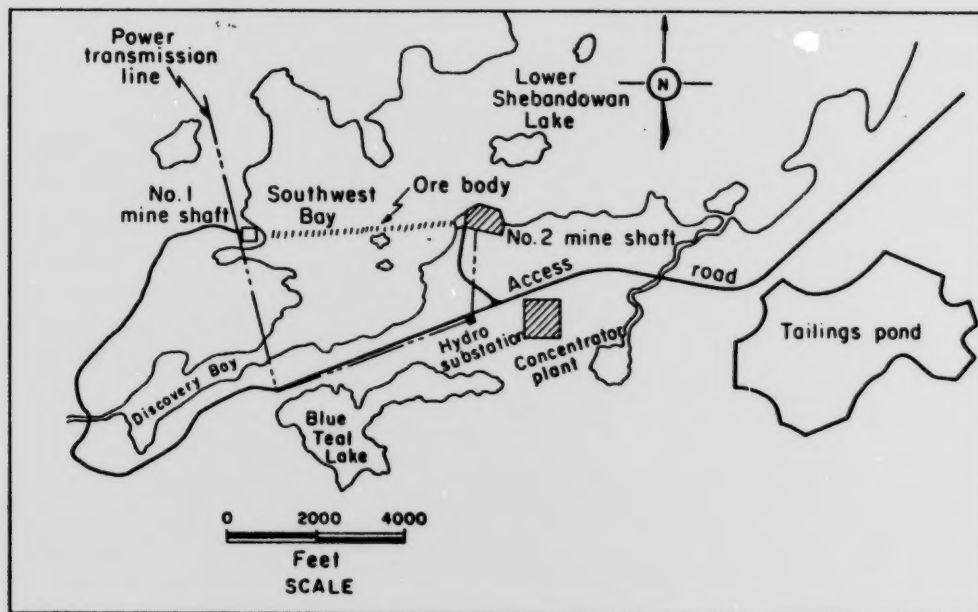


Fig C-3 - Location of mine shafts and concentrator

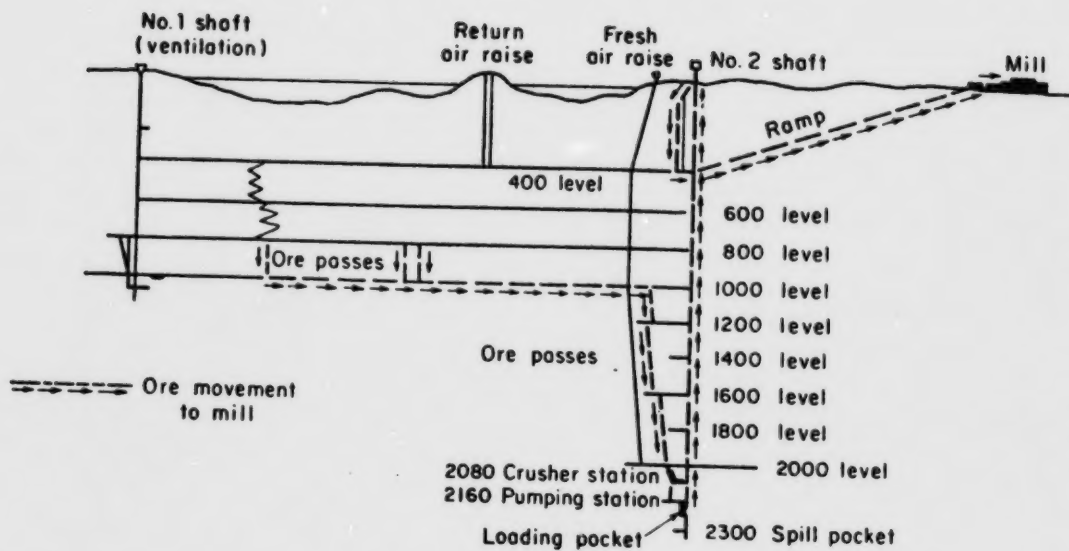


Fig C-4 - Ore movement at Shebandowan mine

Chemicals used in the flotation process include pine oil, potassium amylxanthate and deprimix as a talc depressant. After thickening, the concentrate is dewatered to 18% moisture on a disc fil-

ter and is further reduced to 8% moisture in an oil-fired dryer. It is trucked to a railyard at Sunshine and from there is shipped by rail to Copper Cliff for smelting and refining.

THE PREPRODUCTION PHASE

BACKGROUND

11. In the years before development of the orebody, Shebandowan Lake had gained a wide reputation as a popular vacation centre. Over 750 cottages are located along its shores. Swimming, boating and fishing are popular. Local residents expressed concern over the development of a mine in the midst of their vacationland.

12. Based on concern for environmental protection and to reassure local citizens, the company initiated an intensive environmental study to define the ecology of the region before the commencement of mine operations. This study helped anticipate any adverse effects.

13. No legislation requiring the assessment of environmental impact existed in Ontario or in Canada at the time but had just been passed in the United States (National Environmental Protection Act, 1969). Shebandowan was one of the first mine developments to formally consider environmental aspects in the design of the mine, undertaken not in response to existing legislation, but against a background of developing statutory control. Aquatic and social aspects of the development were recognized as being of the greatest significance. Terrestrial ecology was not overlooked.

TERRESTRIAL STUDIES

14. Surveys were carried out in the early stages of the preproduction phase. Aerial and ground topographic detail was required as basic input for both mine engineering and environmental studies.

15. Timber rights were independently owned, and it was therefore necessary to evaluate the timber resources on the property to help negotiate appropriate levels of compensation. Forest reserves were sampled by estimating tree densities and basal area at intervals along line transects.

16. In addition to environmental staff involvement, the agricultural department was actively concerned in the project. It ensured that soil was removed and stockpiled during construction and that as many pockets of natural vegetation as possible were left in their original state.

RESIDENTIAL REQUIREMENTS

17. A potential conflict existed between the traditional need for a townsite to support the mine and the value of the area as cottage vacationland. A townsite could have detracted from the recreational values. Since 1966, it has been

the Ontario government's policy to reinforce existing towns and avoid residential development spreading into remote rural areas. Hence, the feasibility of a townsite to support the Shebandowan mine was questioned. In 1969, Reid Crowther and Associates prepared a townsite selection study and elementary layout - "The Province of Ontario Report on Site Investigation and Cost Analysis Program Affecting Portions of Sites H and G at Shebandowan, Ontario". The then Ontario Department of Municipal Affairs assessed the extent of support required to provide for a town. With no townsite, the alternative was to provide for a moderate expansion in adjacent centres such as Thunder Bay.

18. Several applications for subdivision of nearby land holdings were received soon after the decision to bring Shebandowan into production was announced. These were refused. Financial support for a local townsite was withheld by the province

in favour of permitting expansion within existing organized and serviced communities. Some of the ramifications of this strategy are discussed in a later section on the Social Aspects of Design.

Aquatic Baseline Studies

19. The objectives of the aquatic monitoring program were to characterize the aquatic environment in the vicinity of the mining operations and to determine the baseline conditions before the mine came into production.

20. The principal watershed drains to the Shebandowan Lake system. Water leaving Lower Shebandowan Lake flows into the Shebandowan River and eventually enters Lake Superior. Gold Creek originates to the south of Lower Shebandowan Lake, near the present tailings area, and joins the Matawin River before its confluence with the Shebandowan River (Fig C-5).

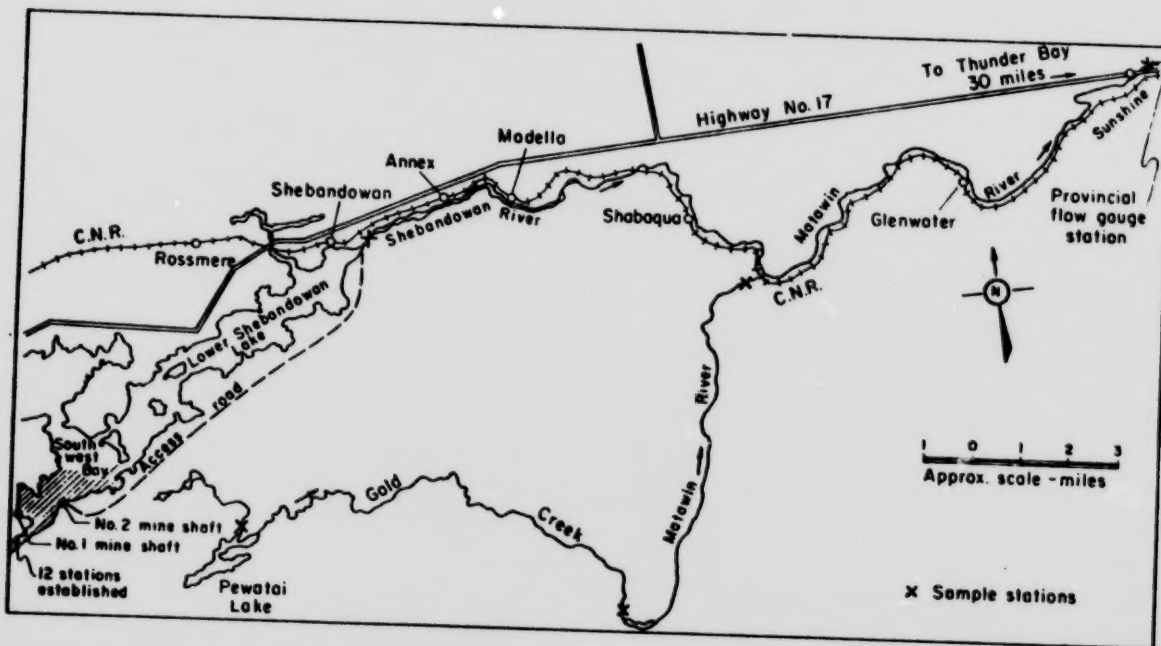


Fig C-5 - Water courses around Shebandowan mine

21. The mine could influence both water courses: the Gold Creek - Matawin River and the Lower Shebandowan Lake - Shebandowan River system. A view of Gold Creek is shown in Fig C-1. The two drainage systems are separated by a height of land but join approximately 20 miles downstream just south of the Trans Canada Highway (Fig C-5).

22. The Ontario Ministry of the Environment (at the time the Ontario Water Resources Commission) in the Thunder Bay region examined the types of problems that might arise and the precautions to be taken. James F. MacLaren Ltd. was retained for baseline studies to examine the aquatic ecosystems in existence before operation of the mine began and to monitor the same parameters after mining had started. Detailed site planning was delayed until after some of the results of the aquatic program were available.

23. Sampling stations were selected to include critical areas such as river junctions and sites representative of the systems to be studied. Appropriate sampling procedures were used at each. An initial reconnaissance was performed in the Shebandowan area before the actual sites were chosen. At that time, the depth of Southwest Bay was determined. Depth profiles for temperature, dissolved oxygen and conductivity were taken with slight variations in these parameters being found. Six sampling stations were then established to monitor water quality. The sampling stations were located in Southwest Bay as this was expected to show the first signs, if any, of the impacts of mining activity. Bottom samples revealed very low numbers of organisms. A further six sampling stations were established in shallower water closer to the mine shafts for benthic studies and to be able to detect changes faster. A seventh sampling station was located at the outlet of Shebandowan Lake. These are the permanent sampling stations for Southwest Bay and Shebandowan Lake.

24. The sampling stations on the more remote Gold Creek - Matawin River system were determined by their accessibility. Four sampling sites were chosen to provide representative samples and were located where major changes in the quantity of water occurred in the system.

25. Lake samples for physical and chemical

analysis were obtained from depths of 3 ft (0.9 m) below the surface and 5 ft (1.5 m) above the bottom sediment. Earlier reconnaissance had shown that the lake has an average depth of 37 ft (11.2 m). It is thermally stratified in the summer months with warm water on top of cooler water. Since the phytoplankton and zooplankton mainly inhabit the upper (photic) zone of a lake, plankton samples were obtained from depths of 3 and 15 ft (0.9 and 4.6 m) below surface. Fish population was estimated by gill-netting or seining. Bottom living organisms (benthos) were collected using an Ekman type dredge to obtain a measured quantity of sediment. The substratum was sieved, and organisms were preserved on site for future identification of species.

26. River samples were taken from selected areas. Benthic fauna were collected with a drift sampler.

27. In the original sampling program it was intended to take samples each month during the ice-free period from May to November. However, because of the lack of accessibility of some of the sites, the sampling program was conducted when access was possible. Physical and chemical parameters were determined each month and the biological characteristics every second month.

28. An adequate baseline monitoring system has to span a period of more than one year. The quantities to be measured change with time and the results of one year may not be similar to those of the second year. Environmental factors, such as climate, may lead to an early or late spring and, therefore, baseline conditions should preferably be established over at least two years or over two ice-free periods.

29. The measured physical characteristics of the water were temperature, turbidity, depth and rate of flow. These properties most clearly influence water quality. Temperature governs the growth rate of biological organisms. Turbidity indicates how much suspended material is in the water from both particulate materials and biological organisms. Depth and flow rates indicate the volume of water available to disperse contaminants as well as natural materials.

30. The chemical characteristics investigated

were conductivity, hardness, alkalinity, pH, colour, dissolved oxygen, nitrogen, phosphorous and heavy metals. These are the characteristics that often determine the growth and productivity of aquatic organisms. They were also most likely to change after mine operations began. The metals chosen for close study were those present in the ore which could also be present in the mining effluent. Many heavy metals can be detrimental to the biota, even at very low concentrations. Other important plant nutrients were added to the list so that changes could be detected early.

31. Impact on aquatic ecosystems cannot always be determined strictly in terms of physicochemical factors. However, the biota that inhabit the water may quickly reflect changes in the water chemistry. Aquatic organisms are in intimate contact with the water - they have no thick cuticles or skin to protect them. They are adapted to specific water qualities. Small changes in water quality may severely retard the health of a population or completely eliminate it. Because of this intimate contact, aquatic organisms often reflect changes in quality before they are detectable by physical or chemical methods. For this reason, bio-assay or toxicological studies of effluents may be required for predicting the effects of pollution.

32. In biological monitoring, a number of communities were examined. The phytoplankton are microscopic algae that are free floating in the photic zone and derive their nutrients directly from the water. Periphyton are usually algae attached to rocks or other living organisms. They also derive the majority of their nutrients from the water. The species in these communities may be arranged according to either their susceptibility to environmental change or to the status of the environment in which they exist. More diverse or varied communities usually survive environmental changes better than less diverse communities. Environmental stress, by affecting species differently, may decrease diversity. Sensitivity is thus shown by both individual species and the population as a whole. This classification by diversity of species and concentration of population can be useful in studying water communities and

understanding the effects of pollution. Zooplankton, the free swimming organisms that feed on phytoplankton and periphyton, and the fish communities were studied less extensively because food chain effects usually take longer to manifest themselves in these higher organisms. However, low levels of materials such as pesticides and heavy metals may accumulate in the higher organisms and have impacts disproportionate to their original concentrations.

33. Benthic organisms were studied since effects of pollutants accumulated in the sediment are often identified first in such communities.

34. The physical and chemical data ranges for the year 1969-1971 are given in Table C-1 for Lower Shebandowan Lake and Table C-2 for the Gold Creek - Matawin River system. The data shown are the ranges of each of the variables throughout the sampling season and at all sample points. Although some parameters show a considerable range of values throughout the season and from year to year, no mining effluents were added during this time. Hence, these parameters reflect the natural state of the waters. They also illustrate the point that monitoring programs should be conducted for more than one year and at a number of different sites within the system.

35. The water has physical and chemical characteristics typical of most Northern Ontario lake systems. The waters are soft with very little buffering capacity and low concentrations of plant nutrients. This is also reflected in the biological communities. The phytoplankton population is extremely low (21 to 66 cells per millilitre of water) and consists mainly of diatoms and Dinobryon spp. However, the presence of Asterionella, Melosira, and Tabellaria as common organisms may indicate some enrichment. With low food supply, zooplankton do not form large populations and average only 1 to 6 organisms per 10 millilitres of lake water. Benthic organism counts are also extremely low. The species found in this lake would be sensitive to the addition of contaminants and are thus good indicators of pollution.

36. In 1969, the conclusions reached after the first year of the survey were as follows:

Table C-1: Water quality data Lower Shebandowan Lake, 1969-71 ranges

	1969	1970	1971
pH	-	-	6.4 - 7.5
Temperature (°C)	6.0 - 21.5	3.0 - 20.0	7.5 - 19.5
Turbidity (J.T.U.)	5 - 10	5 - 5	0.4 - 2.5
Colour (°H)	10 - 20	15 - 15	15 - 50
Conductivity (umhos)	53 - 59	55 - 57	51 - 68
Dissolved oxygen	8.1 - 12.3	9.5 - 10.5	7.4 - 9.8
Total solids	22 - 64	32 - 58	42 - 52
Suspended solids	0 - 1	0 - 1	0 - 10
Dissolved solids	22 - 64	32 - 58	32 - 48
Alkalinity	27.0 - 34.0	19.0 - 20.5	17.3 - 26.0
Total hardness	24 - 29	24 - 27	-
Chloride	1.00 - 1.75	0.75 - 1.50	0.4 - 3.4
Sulphate	-	5.5 - 7.6	5.0 - 9.0
Total nitrogen	0.24 - 0.37	.21 - .45	0.01 - 1.00
Total phosphorus	0.008 - 0.019	0.003 - 0.048	0.005 - 0.090
Total copper	0.007 - 0.050	0.035 - 0.057	0.006 - 0.014
Total nickel	< 0.008	< 0.010	< 0.020
Total zinc	0.014 - 0.060	0.025 - 0.081	0.004 - 0.028
Total iron	0.03 - 0.07	0.02 - 0.06	<0.02 - 0.19

All values mg/l unless otherwise indicated.

- a. The aquatic environment within the study area was found essentially free of inorganic pollutants. The water was soft, with a low concentration of dissolved solids. The components found were considered to be of natural origin.
 - b. Chemical analysis indicated that the nutrients nitrogen and phosphorus were present in concentrations that favour algal blooms. However, biological examination showed that the area was not rich in organisms and had low productivity. Thus, some other environmental condition was creating the limitations.
 - c. The biological flora and fauna exhibited sufficient variety to indicate that the aquatic environment was normal.
 - d. No evidence was found that discharges from temporary waste water treatment facilities during construction were affecting the quality of the Southwest Bay area of the lake.
 - e. It was anticipated that the discharge into Gold Creek from the proposed tailings lagoon would have a high sulphate content. The existing soft water would be changed to moderately hard water, affecting the biological flora and fauna in the creek. To a lesser extent, this might also occur in the Matawin River, particularly at times of low flow. However, the effect on the water quality below the confluence of the Matawin River with the Shebandowan River was expected to be minimal.
37. Conclusions from the 1970 monitoring program were as follows:
- a. The study area aquatic environment was representative of nature, most of the chemical elements being of natural origin.
 - b. It could not be determined how much of the nitrogen and phosphorus already present in some quantity in the lake had been contributed by

Table C-2: Water quality data Gold Creek - Matawin River system 1969-71 ranges

	1969	1970	1971
Ph	-	-	6.5 - 7.5
Temperature (°C)	5 - 24	-	10.1 - 21.0
Turbidity (J.T.U.)	15 - 45	25 - 40	1.1 - 7.0
Colour (°H)	80 - 140	50 - 140	20 - 120
Conductivity (µmhos)	60 - 132	69 - 145	37 - 165
Dissolved oxygen	7.0 - 14.0	8.8 - 10.8	6.9 - 9.2
Total solids	53 - 100	106 - 136	34 - 120
Suspended solids	0 - 9	1 - 10	1 - 10
Dissolved solids	46 - 100	104 - 135	28 - 110
Alkalinity	39.0 - 84.5	27.5 - 68.5	18.5 - 71.5
Total hardness	29.5 - 73.0	42.5 - 70.0	-
Chloride	0.75 - 1.50	0.5 - 1.50	0.3 - 1.75
Sulphate	-	6.1 - 11.9	4.0 - 7.0
Total nitrogen	0.56 - 0.97	0.46 - 0.84	0.52 - 1.59
Total phosphorus	0.035 - 0.061	0.038 - 0.108	0.015 - 0.108
Total copper	0.007 - 0.061	0.014 - 0.025	< 0.006 - 0.017
Total nickel	< 0.009	< 0.010	< 0.020
Total zinc	0.007 - 0.024	0.010 - 0.044	0.008 - 0.360
Total iron	0.48 - 1.17	0.24 - 0.94	0.15 - 0.61

All values mg/l unless otherwise indicated.

local human activities. There had been cottage developments on Lake Shebandowan for some years, which may have contributed these important elements.

- c. There were no significant increases in the levels of nitrogen and phosphorus in Southwest Bay as a result of construction activities in the area. Rather, the lowest values found for these two elements occurred in the general vicinity of the two shaft sites.
- d. The productivity of Lake Shebandowan, contrary to most lake studies in Northwestern Ontario, did not appear to be controlled by nitrogen, phosphorus, silicon or sulphur. Analysis showed that carbon sources were adequate for a healthy environment in the sediment on the floor of the lake. The limiting factor was not determined.
- e. No increase in the low phytoplankton productivity had been observed in Southwest Bay. From this observation, it was predicted that Lake

Shebandowan would not sustain a large fish population.

- f. Other activities, such as logging, on the Gold Creek - Matawin River system might affect the local ecology.

38. Of special note was the inclusion later in 1973, soon after production began, of a complete analysis of all chemical elements (SCAN) of the Shebandowan Project effluent waters. The SCAN results are given in Table C-3 for both mine water and tailings effluent. It was shown that the potential biological toxicants - the heavy metals - were present in very low concentrations. Other studies have indicated that if one of the metals is present at concentrations greater than 1 mg/l, environmental damage can occur. Also, if the sum of the metals, especially lead, zinc, cadmium and nickel, is greater than 1 mg/l, the combined influence of the metals may be detrimental. The analysis showed that these problems were unlikely to occur in the Shebandowan effluents.

Table C-3: Water quality data scan analysis of effluent waters 1973

	Mine drainage effluent March 1973	Tailings effluent April 1973	Tailings effluent August 1973
pH	6.9	7.2	7.2
Sulphate	321	185	161
Suspended solids	23	1	1
Total solids	775	499	406
Copper	0.01	0.01	0.02
Nickel	0.37	0.04	0.04
Iron	2.75	0.32	0.14
Cobalt	0.02	< 0.02	< 0.01
Arsenic	< 0.02	< 0.02	< 0.02
Lead	< 0.05	< 0.01	0.01
Zinc	0.02	0.01	< 0.01
Chromium	0.10	< 0.01	< 0.01
Cadmium	< 0.005	< 0.003	< 0.003
Mercury	< 0.005	< 0.005	< 0.005
Manganese	0.09	0.54	0.25
Magnesium	10.6	12.1	13.0
Aluminium	1.39	< 0.2	< 0.2
Lithium	< 0.01	< 0.01	< 0.01
Molybdenum	0.08	< 0.05	< 0.05
Tin	< 0.05	< 0.05	< 0.05
Titanium	0.078	< 0.05	< 0.05
Chloride	60	31	26
Barium	< 0.2	< 0.2	< 0.2
Sodium	24	91	88
Potassium	3.0	10	1.5
Calcium	157	53	63
Total alkalinity	73	168	122
Total Kjeldahl nitrogen	5.0	4.2	1.7
Ammonia as nitrogen	4.0	2.4	0.4

All values mg/l except pH.

MINE DESIGN AND OPERATING EXPERIENCE

39. Armed with results of the two-year water quality monitoring program, final process design and locating of the tailings pond were completed.

WATER SUPPLY

40. Fresh water is drawn from Shebandowan Lake via a low elevation pump house at the shoreline near No. 2 shaft. The approximate water balance between the mine, tailings pond and concentrator is shown in Fig C-6. Chlorination is carried out before use. Some potable water during summer months has a detectable taste. This may be caused by iron or algal blooms in the lake.

41. With the mine and concentrator working as an integrated unit, fresh water demand is relatively low. Sufficient pumping capacity was installed to maintain an adequate water supply in the event of a malfunction when it might be necessary to run the concentrator on open circuit.

Tailings Disposal

42. The tailings disposal area plays an intricate part in the overall operation of the complex, with recycled water for the mining and milling operations being taken from the tailings pond. Almost 2 million gallons (9 million litres) of

this water are recycled between the tailings pond and the mill each day.

43. The results of the water quality monitoring program and projections of types and levels of contaminants that could be expected showed that disposing of excess water into Shebandowan Lake would have a small impact on the local ecology. The tailings pond could have been located in a convenient valley near the concentrator adjacent to the lake. The concentrator would then draw its process water from the tailings pond with a comparatively small net discharge of clean effluent to the lake. Although acceptable on technical grounds, such a location would have received strong opposition from residents and the Ontario Water Resources Commission. Accordingly, a site near and discharging into Gold Creek was selected that met all engineering, social and environmental requirements. A recent aerial view of this site is shown in Fig C-7.

44. The 300-acre (140 ha) tailings pond was designed to be sufficient for the 20-year life of the mine. After cyclone separation of the coarse tailings for underground backfill, the fine fraction is pumped one mile (1,600 m) east to the tailings pond. After settling in the tailings

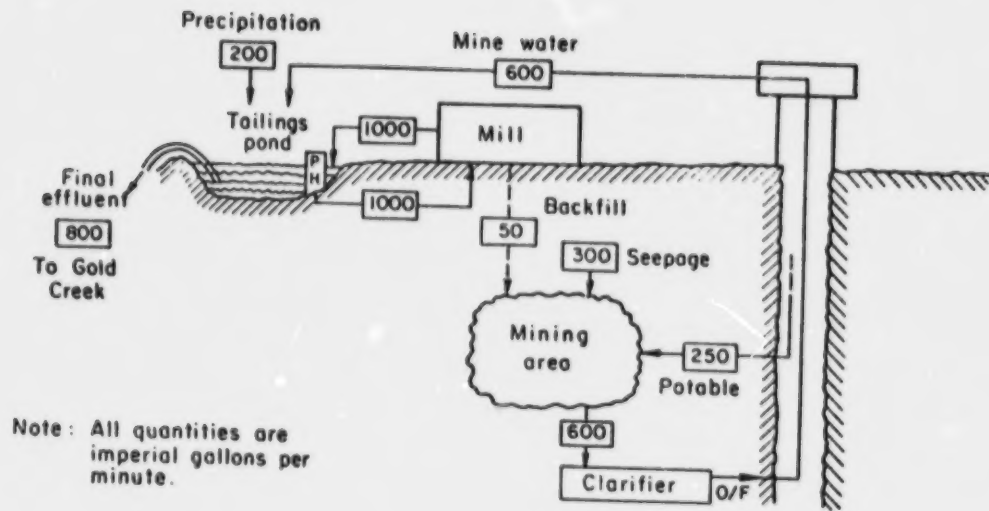


Fig C-6 - Schematic water flow at Shebandowan mine



Fig C-7 - Aerial view of tailings pond in late 1974

pond, water is recycled directly back to the concentrator.

45. One major drawback to the settling of tailings in open impoundments is resuspension of particles by wave action, which occurs even in light winds. The tailings pond was originally a peat-filled tree-covered depression. Rather than remove the trees, their value in reducing wave action and thus promoting more efficient settling was recognized. Originally hydrogen sulphide was produced due to anerobic decomposition of the organic material. This was related to turbulence induced at the return water pump house intake. This localized problem was corrected by relocating the discharge from the return pump overflow which reduced local turbulence. Four 4-in. (10 cm) fixed siphons are used to regulate the outflow from the pond so that it remains proportional to the rate of flow of water in Gold Creek.

Control of Contaminated Water

46. Two tailings lines were installed, leading from the concentrator, one being a spare. Suitable natural depressions were prepared at low points along the route to be available as emergency sumps. Sumps have a graded rock base and are equipped with dump valves. A portable pump is available for rehandling material from the sumps should the need arise.

47. The other source of contaminated water is drainage from the mine itself. The mine water is collected underground and treated using a complete system of chemical feeders, a clarifier and vacuum filters. Originally, this treated water was to be pumped directly into the Gold Creek - Matawin River system. However, the underground mine water would not respond to clarification and was not a good enough effluent for direct discharge (Table C-4). On the other hand, the tailings water was

Table C-4: Water quality data mine drainage analyses 1971-73

	Mine drainage effluent 1971	Mine drainage effluent 1972	Mine drainage (as flow to tailings pond) August 1973
pH	6.9 - 7.6	6.6 - 7.9	6.9
Turbidity (J.T.U.)	14 - 60	320	-
Colour (°H)	-	3.0	-
Suspended solids	8 - 102	144 - 766	23
Alkalinity	22 - 73	350	-
Total hardness	-	571	-
Sulphate	21 - 440	54 - 650	321
Total copper	0.052 - 0.242	1.3 - 1.5	0.01
Total nickel	0.100 - 0.240	0.6 - 1.4	0.37
Total zinc	0.018 - 0.033	< 0.1	0.02
Total iron	2.68 - 7.38	12.7 - 21.8	2.75
Conductivity (µmhos)	141 - 1260	-	-
Total solids	106 - 1104	-	775
Dissolved solids	98 - 1002	-	-
Chlorides	9 - 102	-	-

All values mg/l unless otherwise indicated.

of sufficiently good quality for direct discharge (Table C-3). After the start of mining operations, the treated mine water was directed to the tailings pond. Excess water from the tailings pond was discharged to the receiving streams. Actual operating experience did not confirm the original predictions about the quality of mine drainage. Sufficient factual information was available from the monitoring program to assess the situation and make the appropriate changes. Figure C-6 shows schematically the present overall water balance.

48. As a precaution to help control surface run-off that could be significantly contaminated with oil and grease, areas adjacent to the service buildings have been asphalted. Additional precautions have included diking, rerouting streams and installing appropriately sized culverts at road crossings.

49. Septic tanks were provided by the contractors for their own work crews living in trailer accommodation near No. 1 shaft during the development phase. The baseline water quality monitoring program did not reveal contamination of the lake water from this nearby potential source of pollution.

50. All plant sewage is disposed of via a separate 4-in. (10 cm) diameter polyethylene pipe to the tailings pond. INCO's previous experience elsewhere had shown this to be an adequate arrangement. A chlorination facility is provided on a standby basis. Coliform levels are monitored regularly.

Aesthetics, Noise and Dust

51. The position of the mine shafts and headframes were dictated by the location of the ore-body; consequently, they are close to the shorelines. No. 1 shaft headframe has since been dismantled and area rehabilitated (Fig C-8 and C-9). This cleared area remains partly visible across Southwest Bay. The No. 2 shaft headframe is the only significant indication that a mine is operating in the vicinity. A return air raise is located on a small island in the centre of Southwest Bay; this ventilation raise is so well camouflaged that few people are aware of it.

52. Primary crushing, storage above the 400 level and conveying ore underground to the fully enclosed concentrator about a half a mile (800 m) inland all serve to reduce noise levels across the lake. Atmospheric dust is likewise minimized.

53. Built for efficient transportation of concentrates, a quality paved road links the mine to Highway 17 and the rail siding at Sunshine. To minimize dust losses and environmental problems from dried concentrates, truck boxes are covered with tarps. This main access and haulage road is now maintained by the Ontario Ministry of Transportation and Communications, which is also responsible for snow clearance.

Social Aspects

54. There is no townsite associated with the Shebandowan mine. The predicted life of the mine is 20 years. There were fears that the greatest environmental impact would arise from development of a townsite to house the 350 workers. The Provincial Government decided that creating a potential ghost town had to be avoided. Furthermore, provincial participation to provide the necessary infrastructure for a new town could not be justified on financial grounds. It is normal to make cost-benefit calculations for a 50-year period.

55. A commuting trip of one hour is considered by planning officials to be about the maximum that employees at a new operation can reasonably be expected to undertake. The majority of the workers live in Thunder Bay and can travel to work by local bus. Because of the relatively long time spent in travel to and from work, the mine and mill operate four 10 hour shifts per week.

56. There have been moves to winterize summer cottages which would make them suitable for year-round occupancy by mine employees and hence change the character of the area. Such moves were discouraged, in part, to avoid later demands for public services like paved roads, school buses and snow clearance. Most local cottage roads are privately owned and maintained. Outside the immediate vicinity of the mine, few developments have occurred that can be attributed, even indirectly, to the presence of the mine.

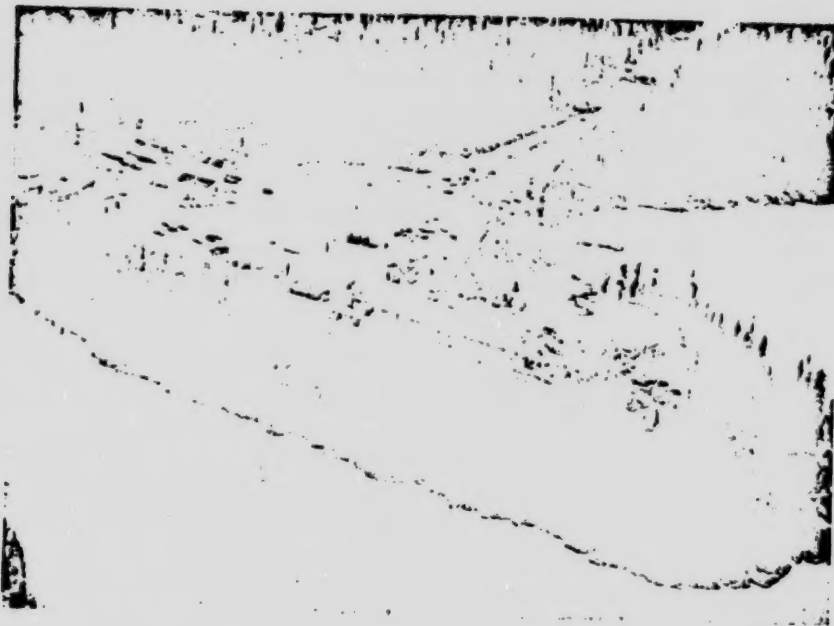


Fig C-8 - Shaft No. 1 with development work in progress



Fig C-9 - Shaft No. 1 after contouring and seeding (October, 1974)

57. Local cottage owners originally expressed strong opposition when the mine development was first announced. The initial alarm, distrust and opposition at having a mining operation seemingly thrust upon them, in the midst of their vacation land, was dispelled by the open door policy adopted by the company. In addition to a formal public hearing when the decision was made to

develop the deposit, meetings with the public and local associations were held to provide an opportunity for the residents to express their concerns and for the company to explain the way they intended to develop the mine. Fostered in part through an annual newsletter to all residents from the company, a close relationship has since developed between the company and residents.

RECLAMATION

LANDSCAPING

58. It is the visual or aesthetic aspect of a mine that so often causes people to perceive a pollution problem. It is important to rehabilitate all areas disturbed by construction as well as areas affected by later mine operations.

59. The company's agricultural staff was involved during construction and ensured that, in

addition to leaving as many pockets of natural vegetation as possible, soil, rocks and other forest debris were saved to help in reclamation.

60. By 1972, when the complex was nearing completion, a program to rehabilitate the area was instituted. This was begun at the No. 2 shaft and concentrator locations. Figure C-10 shows activity near the concentrator in preparation for



Fig C-10 - Regrading prior to revegetation at the concentrator



Fig C-11 - Aerial view of the concentrator after rehabilitation

revegetation. Figure C-11, taken in 1974, shows the extent of the rehabilitation work that had been completed.

61. The aim was to return affected areas as nearly as possible to typical Northern Ontario forest conditions. Rehabilitation of sites included collecting scrap material and either selling or burying it. The waste rock dumps were contoured to complement the natural physiography. There was no desire to create a flat grassland interspersed with exotic tree species, but rather to retain the natural topography and vegetation. To this end, the occasional large rounded boulder, indigenous to the region, was left exposed. Soil was spread to a depth of about 4 in. (10 cm) over the waste rock surface. Forest debris, such as large tree roots, which had been left in the preserved soil, served to trap moisture and minimize erosion on the slopes. Figure C-12 shows soil being placed on a contoured rock slope, illustrating the use of natural debris. Ferti-

lizer was added to the soil. Grass species were introduced along with companion crops of rye or oats. Only native tree species have been used in the plantings in 1974 and 1975. The agricultural staff has also experimented with different fertilizer rates to encourage native species to encroach upon the grassed areas. At No. 2 shaft, the number of tree plantings was increased near the lakeshore as no belt of trees was left as camouflage when the area was originally cleared.

62. Figures C-8 and C-9 show the scope of rehabilitation required at No. 1 shaft after the contractors had left. The headframe has since been removed. The shaft is used only for ventilation. As activity is now centred across the lake at No. 2 shaft, a beach and picnic area was created near the No. 1 site for the benefit of local residents.

63. Pipelines to the tailings pond have been buried, covered with soil and revegetated using a hydroseeder to place mulch, seed and fertilizer

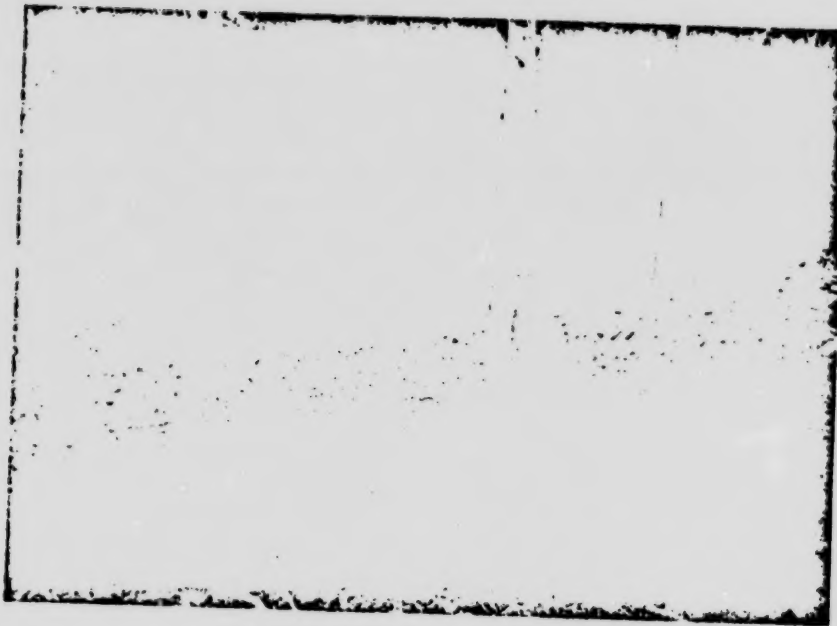


Fig C-12 - Rock dump reclaimed using soil and forest debris

(Fig C-12). The broad cleared areas along the access roads were grassed in 1973 using similar techniques.

TAILINGS REVEGETATION

64. Drawing on their extensive experience of revegetating the Copper Cliff tailings, the agricultural staff is devising a method suitable for

the Shebandowan tailings area. The area will be revegetated progressively as each portion of the pond is filled and after allowing a suitable period for the tailings to dry out. Initially, it is proposed to revegetate with the same plants as those at Copper Cliff, with the subsequent introduction and encroachment of native trees being encouraged.



Fig C-13 - Tailings pipe lines revegetated after being buried

CONCLUSION

65. If the property had been developed according to short-term economic criteria alone, it is quite likely that part of Lower Shebandowan Lake would have been drained to permit mining by open-pit methods. This was not acceptable because of the value of the area for recreational purposes.

66. Shebandowan is among the first Canadian examples of extensive, formal environmental studies being carried out before and during the development of a mine.

67. The physical, chemical and biological monitoring system was started during the mine start-up and is continuing. No change in the aquatic environment has been detected since the baseline monitoring program was completed.

68. As a result of the company's open door policy, especially in the early stages of development, initial local resistance to mine development has been dispelled. It is now common for citizens to bring their own technical problems, such as septic tank layouts, to the company staff. The

grounds of the complex are always open to the public. Regional planning officials have successfully avoided residential developments that could have reduced the natural attractions of the area.

69. The Shebandowan experience has shown that environmental considerations can be effectively incorporated into mine design with relatively minor additions to capital requirements. Monitoring of key environmental parameters at the initial stages and during production can identify problems before they cause major damage. In this way, environmental degradation and costly remedies can be avoided. Operating costs attributable to environmental considerations are considered to be minor at Shebandowan. No staff is assigned to environmental protection exclusively, although expert assistance is available from the Sudbury operations. Three years after production began, activities associated with maintaining a quality environment were effectively integrated into the normal routine of local management and supervision.

TAILING DISPOSAL IN CANADA

By

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INTRODUCTION⁽¹⁾

The first fifty years of the 20th century may be noted for the introduction and improvements in processing equipment, technology and milling methods in the ore dressing industry as summarized below.

At the close of the 19th century, gravity concentration was the chief method of beneficiation of ores and the cyanide process was beginning to find its way into the gold mills. The most important problem facing the mill operator at that time was the influence of particle size since the production of a minimum amount of fines is the key to efficient concentration by gravity means.

With the introduction of flotation, metal recoveries increased by 20% to 30% and grinding problems became less acute since flotation is more efficient than gravity concentration in the recovery of values from fine sizes. Thus flotation can probably be considered the greatest single development in milling methods prior to 1950. It is predicted that the second half of this century will be noted for its treatment of low grade ores, large equipment, high tonnages, instrumentation and process control.

Unfortunately, this progress is not without its difficulties and plant size is a contributing factor. The magnitude of most new milling projects since 1950 has been such that they have attracted the attention of an endless number of politicians, regulatory authorities, revenue collectors, environmentalists, extremists, etc. Nowhere in the mining industry is this more obvious than in the process waste storage schemes. Disposal of the mill tailing from all concentrators and particularly from the larger ones has become a major feature in concentrator design and operating procedure. Not only do the owners have to plan for the disposal of large quantities of solid rejects but they also have to consider the recycle of water, the treatment of net effluents, the control of dust, the aesthetics and the rehabilitation of the sites (in a suitable manner) at the conclusion of operations. These factors have become integral and major features of today's ore dressing plant capital and operating considerations.

Most provinces and the Federal jurisdictional areas now require extensive environmental impact studies, detailed tailing disposal construction and operating plans (frequently designed and/or approved by independent soil engineers) and approval is given in many applications only after public hearings are held. In some instances it is necessary to post bonds to cover the cost of rehabilitation and maintenance at the termination of activities. To compound his problems, the Canadian mill operator, unlike the majority of his American cousins, must compress his tailing dam construction into the 6 to 8 months of non-freezing weather while during the winter operating months he must contend with extended periods

of temperatures around minus 40 degrees centigrade. Principally because of this, most operators consider it good practice to have a minimum of 1½ years tailing storage capacity ahead of need to guard against lost construction time due to labour unrest, equipment breakdowns, potential tailing area problems, inclement weather, etc.

When it is recognized that fewer than 25% of all currently operating milling plants in Canada were operating in 1956, one will understand why ore dressing practice in the past 20 years has made such dramatic advances. A comparison by groups might be even more startling. None of the current potash mines was operating prior to 1956, the uranium mines in Ontario started up in the late fifties; there were few ferrous milling plants to refer to in the last milling volume; over 75% of the plants which produce copper, copper-nickel or copper-molybdenum concentrates started up after 1956; almost all of the operating gold mills were in existence prior to that year.

As fewer and fewer high grade deposits are discovered and developed and more are depleted, the importance of the lower grade deposits increases annually. However, to justify their development, the ore reserves must be significantly higher and the average milling rates generally much greater. These facts have necessitated the use of different mining techniques so that the majority of new mines in Canada have used open pit methods to extract their ore. Few of the newly developed underground mines use the familiar small tracked equipment so that most of today's underground mining operators use large, off-highway load, haul and dump machines similar to those used in open pits.

2. TAILING CHARACTERISTICS

As the mining and milling technology has had to change with the available ore, there have been significant changes in product quality - both concentrate and tailing. Since comminution is normally the largest individual operating cost, the trend and desire of the milling profession is to do the least possible grinding consistent with throughput, grade control, recovery and economics. Thus the trend is for a coarse grind on the majority of the ore and regrinding of intermediate products only if necessary. This trend, along with the fact that fewer underground mines which require backfill are being operated, has meant that today tailings dispatched for disposal are generally coarser and more difficult to transport but also are significantly more suitable for bank building.

With a few notable exceptions, the new milling operations do not need to grind their ore finer than 45% to 65% minus 200 mesh. In general, the more complex ores such as the copper-zinc and copper-lead-zinc require a finer grind while the potash companies prefer not to grind at all if possible. Since degree of grind also affects solubility and therefore effluent quality, the mill operator today must balance the beneficial effects of size reduction versus the problems which might be caused by over-grinding. Near-surface and therefore open-pit-able ores have the disturbing tendency to be more altered, more soluble and softer so that side effects of the recovery process may cause problems in tailing disposal. Fortunately, (from an environmental viewpoint) the lower grade ores are frequently lower in total sulphides and therefore less liable to create acidic pollutants.

3. PUMPING

While earlier in the century a high percentage of the milling plants were able to dispose of their tailing by gravity in launders or through pipe lines, over 80% of the Canadian operating plants today must pump their waste. The vast majority of the pumps used in Canadian operations today are of the rubber-lined centrifugal type. Some exceptions are in the potash operations and occasionally in others when higher pressures are required such as in series arrangements. Under these circumstances some operators prefer all metal pumps or, as a minimum, all metal impellers.

No longer does the Canadian operator shun series slurry pumping set-ups. It is quite common now to find two stage arrangements although rarely is it necessary to go beyond this number. However, commencing with the Milliken Lake operation in the late fifties, pumping arrangements with three and four stages have been designed and are in operation. The preferred arrangement, if any of these series pumps should be variable speed, is to have this control on the first stage for a "soft" start.

4. PIPE LINES

Whereas in the United States (and perhaps other countries) it has been common practice to use concrete or asbestos cement pipe, the majority of the older Canadian operations have preferred wood stave pipe for tailing transportation. The reasons for this were: price, availability, wear characteristics and insulating value. However, the changes in the technology and economic conditions over the past 10 years have altered the

situation so drastically that few new or replacement lines have been assembled with wood stave pipe. The majority of the latest Canadian designs have specified polyethylene pipe except when higher pressure installations dictated the use of ductile iron, rubber-lined steel, or other specialized pipe. Polyethylene is not without its problems but the installation and operating expertise is now available so that the operators can expect good performance.

There is little in common in the densities of slurries pumped because thickening is not normally required in Canada for water conservation or immediate recycle. The range of percent solids may be from 10% to 50% by weight. Nevertheless, when the mill superintendent has a choice, he appears to choose between 20% and 30% with flow rates between 5 and 7 feet per second - with an exception as a group being the ferrous industry who use velocities closer to 10 feet per second. Since location tends to dictate line slopes, the variations are considerable but when a choice is possible the selections fall between 0.5% and 1%. Drop towers are frequently used to reduce slope in excessively steep sections.

While the practice is by no means universal, it is common to provide a spare tailing line and/or an emergency dump system. The exceptions appear to be principally a matter of economics or uniqueness of installation.

5. TAILING DAMS

A. Construction and Operation

Past practice is not an adequate guide to tailing dam construction today. By hard work, sound judgement, good

luck and favourable topography, yesterday's mill operators built and operated many successful tailing dams. They were fortunate in that tonnage rates were relatively low and therefore build-up slow, deposits were well compacted and space near the concentrator was available. Nevertheless, there are examples that are not exemplary which have tended to give the activists ammunition.

Today high and/or large dams in difficult terrain or near heavily populated areas are required to contain the large volumes of tailings produced. Even the small and the remote structures can endanger mankind, affect the environment, or offend the sensitive so that all tailing dams are considered as civil engineering structures and, as such, are being adequately designed, built and monitored. There is no doubt that this procedure increases the cost of waste disposal but it is recognized as a corporate responsibility whether or not it is a permit requirement.

Since 75% of the Canadian operating concentrators were designed and built in the last 20 years there had to be a corresponding number of tailing disposal systems inaugurated. Almost without exception (particularly with the higher dams of the past ten years) the owners have consulted with soils engineers during the design of their dams and retained them during the operating phase. Stripping of vegetation and overburden in the area of the proposed banks is universally the initial preparation followed by the installation of suitable keys and subdrains. Additionally, if the owners have chosen to withdraw the supernatant water from the tailing pond by decant towers and pipes through the bank they

must be installed before any banks may be built. The first dams are built preferably with local material if it meets with engineering standards for permeability, compactibility, flow characteristics, earthquake resistance, etc. Frequently, it is built with the stripping material (not the overburden) from the mine open pit since its principle cost is only that of the additional haulage distance.

Operators prefer to use tailings for subsequent lifts because there is plenty of material on site and therefore the cost is low. As mentioned previously, concentrator tailings today are generally coarser, due to the fact that backfill has not been extracted and due to the high tonnage rates, so that the sands frequently make ideal bank building material. Since spigotting from pipes on the banks tends to yield some favourable segregation leaving sands at the periphery and allowing slimes to migrate towards the centre, many operators find this the cheapest method of disposal and source of construction material. Most of the older plants had adapted variations of this method of upstream dam building at start-up and still carry on with the practice. (See Figure No. 1.)

This "upstream" method of construction is frowned upon by many soils engineers today because it is claimed that layers of slimes accumulate under the subsequent principle support of the dam structure. With high dams and with poor draining materials this may tend to weaken the structures and therefore it is only used to a limited extent in new dams.

When spigotting does not yield suitable material for construction, cyclones are commonly used to produce a classified product with better drainage and stability characteristics.

The majority of dams constructed in the past 10-15 years in Canada have been raised with cycloned coarse tailings using centre line or downstream methods. No doubt, the adaption of this philosophy has been influenced by the height of the dams, the earthquake potential, the input from soils consultants and the increasingly strict regulations.

B. Select Methods

For various reasons, some operations cannot use mill tailings for construction and they have carried on with waste rock and/or local materials. Obviously the potash operations cannot use their tailings because of solubility and the rule of the day in Saskatchewan is to use local, well compacted clays. In addition, these dams are built as impervious water dams because the brine must be reused to minimize the soluble losses, the effects of pollution would be serious and fresh water is an expensive commodity in the province.

Another unique method of tailing disposal in Canada is exemplified by the scheme at the Ecstall operation of Texasgulf Sulphur⁽²⁾. Their tailing disposal area consists of 3,000 acres enclosed by a gravel dyke. Mill tailings are thickened and pumped to a central spigotting location inside the dam. The system is designed to build a mountain of tailings in the central area and thus keep the height of the perimeter dyke to a minimum.

Two of the operating plants in British Columbia are close enough to the sea and to relatively deep water that they do not have to construct dams. Utah Mines Limited,

Island Copper Division⁽³⁾ conducted lengthy studies and held many public hearings before undertaking underwater disposal. Their unique system involves the dilution with sea water prior to introducing the tailings to the ocean at a depth of 150 feet in a marine fjord system. Their monitoring and control schemes show that they are meeting all required objectives.

Although there are no specific unusual features about their methods of disposal, two additional milling plants in B.C. discharge their tailings underwater into the ocean. Another disposes of its tailing a minimum of 100 feet below the surface of a fresh water lake after treatment with chlorine, lime and flocculant. A small number of operators in Eastern Canada are fortunate enough to be able to end-spill their mill waste into a natural or man-made lake and simply control and/or treat the net effluent from the system.

6. METHODS OF WATER REMOVAL

As noted previously the great majority of milling operations in Canada impound their tailings behind dams and in recognizable disposal areas. As most milling operations are wet and have a tailing slurry density between 10% and 50% solids, and as the Canadian climate is not conducive to high solar evaporation rates, it follows that most milling operations must have a reliable functional method for removal of the supernatant water from the disposal area.

The majority of the operations remove the supernatant water from the tailing by settling followed by decantation

while the minority use spillways or weirs as noted in the following summary:

TABLE I

<u>Method Employed</u>	<u>%</u>
Decantation	56
Overflows	29
Not Stated Or Not Required	<u>15</u>
TOTAL	100

Decantation is accomplished either through the use of towers located in the pond area or through the use of floating pumps. Permanent decant towers normally constructed of concrete but occasionally of steel pipe, coated for corrosion protection if required, are the most common. The advantages come from a low operating cost and the flexibility to be grossly oversized to handle spring runoff at a very nominal increase in capital cost. The disadvantages are that they are in fixed locations, structural design must be rigorous and, should they fail by shifting or plugging, remedial measures are limited. Floating pumps on the other hand have a higher operating cost, are dependent on a source of power, are more flexible in location, and are exposed for quicker maintenance.

Of the two methods of decantation, the use of permanent decant structures is the more prevalent. Further breaking down of the previous summary shows the following:

TABLE 2

<u>Method of Decantation</u>	<u>%</u>
Permanent Decant Structures	73
Floating Pumps	<u>27</u>
TOTAL	100

The use of floating pumps in Canada appears as a recent practice. Most of the plants using this means of decantation have been built within the last 10 years, have larger than average milling capacities and expect tailing dams with high ultimate heights.

Most operations which anticipate an ultimate dam height of 200 feet or more appear to prefer floating pumps to permanent decant structures as the following Table suggests.

TABLE 3

<u>Operations</u>	<u>Ultimate Height</u>	<u>Method</u>
Case 1	470	Floating Pumps
Case 2	415	Decant Towers
Case 3	315	Floating Pumps
Case 4	300	Floating Pumps
Case 5	275	Floating Pumps
Case 6	265	Floating Pumps
Case 7	230	Floating Pumps
Case 8	200	Floating Pumps
Case 9	200	Decant Towers

7. CLARIFICATION

The reported use of a clarifying pond following the removal of water from the tailing pond is variable. The purpose of the clarifying pond is to provide additional reservoir capacity or to improve the water quality by settling or aging, with or without additional chemicals before reusing the water in the process plant or discarding it to the environment.

The following Table shows the relative prevalence of clarifying ponds.

TABLE 5

<u>Practice</u>	<u>%</u>
With Clarifying Pond	50
Without Clarifying Pond	31
Not Stated Or Not Required	<u>19</u>
TOTAL	100

It should be noted that those operations employing floating pumps do not use clarifying ponds primarily because their incorporation would serve no useful purpose and those operations which discharge their tailings to a natural lake or the sea do not require them.

8. RECYCLE

The amount of water to be discarded to the environment by those operations which impound their tailings is primarily determined by the ability to maintain a stable and satisfactory

water balance throughout the processing and impoundment systems. New water from a fresh water source enters through the process, by ground water and production water from the mine and by precipitation. Water remains tied up in the system by entrapment in the consolidated tailings or leaves with the concentrates or by evaporation. The sum of these flows provides the supernatant water on the pond.

If the new water inflow is greater than the water leaving the system then the quantity in the pond will increase and, to maintain a balance, water must be removed from the system and discarded. The practice of recycling from the impoundment area can reduce the amount of fresh water required and the amount of used water to be discarded. However, only in very rare cases can the discarding of water in Canada be reduced to zero because precipitation over the drainage area of the system has such a pronounced effect on the overall balance and because definite irreducible quantities of new water must be used in the process.

The general trend in the industry, particularly apparent in the newer concentrators, is an increasing use of recycle water from the tailing disposal system. The following Table shows the prevalence of the practice of recycling.

TABLE 6

<u>Practice</u>	<u>%</u>
Recycle	51
No Recycle	42
Not Stated Or Not Required	<u>7</u>
TOTAL	100

That the new concentrators are more prone to practice recycle of their effluents is suggested in the following Table concerning those plants commencing operations since 1960.

TABLE 7

<u>Practice 1960 To-Date</u>	<u>%</u>
Recycle	70
No Recycle	25
Not Applicable	<u>5</u>
TOTAL	100

The incentive to use more recycle water can arise from economic or environmental considerations. The economic justifications can be apparent if the cost of procuring adequate quantities of fresh water is high relative to the costs of recycling, or if some residual reagents can be returned in the recycle water thereby lowering the consumption of reagents.

There can be constraints on where recycle water can be used in a concentrator. Returning reagents or their breakdown products can have deleterious effects on complex separation circuit metallurgy or returning frothers can readily upset a delicate cleaning circuit. Because recycle water invariably contains both dissolved and suspended matter, it is not ideally suited for use in pump glands or for equipment sealing and cooling.

9. TREATMENT

The practice of chemical water treatment is erratic but, where it is used, lime is the favoured chemical as the following Table suggests.

TABLE 8

<u>Practice</u>	<u>%</u>
Lime Treatment	23
Other Treatment	10
No Treatment	55
Not Applicable	<u>12</u>
TOTAL	100

Treatment is used to improve the quality of water either before recycle or before discard and lime is used as the principal chemical for its flocculating effect to improve water clarity or for its alkalinity to promote precipitation.

While most tailings, as they leave the concentrator, are neutral to highly alkaline there are numerous examples where under a select set of conditions the pond can become acid. Discarding a strongly acidic effluent is not permissible under the guidelines. Moreover the acid water dissolves more of the objectionable heavy metals which are generally identified by the environmental authorities.

A prerequisite for a tailing pond to become acid is a sufficient concentration of thiosalts or sulphide minerals which can oxidize to sulphates. Problem concentrations of thiosalts are usually associated with the processing of high sulphide ores and the thiosalts appear to be generated

throughout the grinding, conditioning, flotation and thickening circuits. Additionally, the use of some reagents, such as sulphur dioxide, can augment the naturally generated thiosalt concentrations. The availability of oxygen and an elevated temperature promote the oxidation of the thiosalts to sulphates. For this reason some untreated tailing ponds in summer can become acidified to pH 3.5 and return to pH 7.0 or above in the winter.

An additional problem encountered by those who process high sulphide ores is that of handling acid mine water and acid tailing dam seepage. This water which in extreme cases may have a pH of 1.5 can in rare cases, be pumped back to the tailing pond but usually this practice promotes water quality problems within the pond. The preferred method is to treat the acid water with lime, oxygen and flocculent in a separate treatment system with return of the resultant sludge to the tailing pond and reuse or discard of the clarified water.

The uranium operations customarily treat their clarified effluent from the tailing pond with barium chloride to form an insoluble barium radium sulphate precipitate in a holding lagoon prior to discarding the effluent. The iron ore operations generally use flocculents such as lime, alum or other proprietary chemicals.

Passive water treatment is accomplished through aging either in the tailing pond or in a storage reservoir. This treatment relies on light, oxygen, heat, natural evaporation and time to remove, destroy or break down organic and other miscellaneous compounds which have been added during the processing of the ore.

10. WATER DISCARD

The terms and conditions under which water may be discarded from a tailing disposal system have changed markedly since the 1957 predecessor to this volume was issued. Today it is commonplace that the quantity and quality of water discarded is regulated by a Government authority.

Most provincial governments have established effluent disposal regulations or guidelines as have the Federal officials. Although there is only a nominal similarity amongst these regulations and guidelines now they are expected to become more similar and more restrictive.

The following Table illustrates the current, averaged range of effluent standards or guidelines established by the various jurisdictions. Only the more common elements or compounds are noted and the values listed are neither the most stringent nor the least restrictive. Further, in some cases there are provisos that the cumulative concentrations of selected heavy metals (copper, lead, nickel and zinc) shall not exceed a total of 1.0 mg/l, or that the concentrations of some elements (cadmium, mercury) shall not be above background levels.

TABLE 9

<u>Element or Compound</u>	<u>Effluent Guidelines in Mg/l (ppm)</u>
Solids Dissolved	2,500 or less
Solids Suspended	15 to 50
pH	6.0 to 10.0
Arsenic	0.05 to 0.25
Cadmium	0.005 to 0.02
Chromium	0.05 to 0.5
Copper	0.03 to 0.3
Cyanide as CN^-	0.02 to 0.1
Iron	0.3 to 1.5
Lead	0.05 to 0.2
Mercury	0.001 to 0.005
Molybdenum	0.5 to 1.0
Nickel	0.3 to 1.0
Sulphate as $\text{SO}_4^{=}$	50 to 500
Zinc	0.15 to 1.0
Radium 226	10.0 pCi/l

Most mining operations today, whether they dispose of their tailings on land or underwater, or whether they practice zero recycle or total recycle of water, are under permit. Normally, prior to issuance of a permit, the tailing dam structure must be approved by an accredited soils engineering consultant and the permit usually defines:

1. Tonnage and volume of tailings to be disposed;
2. Quantity and Quality of the supernatant water on the pond;
3. Quantity and Quality of water discarded;

4. Detailed water quality monitoring program;
5. Reporting dates.

The permit also provides access at any time to the mine property for a representative of the regulatory authority and empowers him to close the operation if there is a perceived danger or an infringement of the permit.

A unique means of excess water disposal is employed by most of the potash plants operating in Saskatchewan. Excess water in the form of a sodium chloride brine is pumped down a drill hole to the Deadwood Sands formation located some 5,000 or more feet below surface.

11. REVEGETATION

The principal reasons for the revegetation of tailing dams might be:

1. Aesthetics;
2. Minimization of a dust source;
3. Minimization of erosion;
4. Water management - control of seepage;
5. Land reclamation
6. Compulsion.

The practice of revegetation has not become universal as the following Table suggests.

TABLE 10

<u>Practice</u>	<u>%</u>
Revegetation	27
Experimental Revegetation	14
No Revegetation	56
Not Stated or Not Required	<u>3</u>
TOTAL	100

As tailings are nominally ground up rock, there is very little natural plant nutrient to be found on the areas of tailing dams for which some revegetation is contemplated. Moreover, the age of the tailing dam and particularly the mineralogy of the ore deposit processed have a pronounced effect on the ability or practicality of commencing and sustaining a vegetative cover.

In general, revegetation problems and costs increase from the relatively inert highly siliceous tailing to the reactive massive sulphide tailing with its concomittent high contents of pyrite and pyrrhotite. Newer tailing dams often can be more readily revegetated than old or abandoned dams because of current dam design and operating practice and because the effects of aging and oxidation are not so advanced. There are a few examples in which old reactive tailing areas have been covered with clay and soil to facilitate the growth of vegetation. However, there remains the problem of maintaining slope stability on the peripheral dikes and the possibility of upward leaching by acidic solutions which are toxic to plant life.

Depending upon the specific circumstances, a revegetation program for a tailing dam can be divided into four phases and can take from a few to many years to complete. Because agronomy is not normally within a mill man's field of competence, very productive and useful assistance can be obtained by retaining a qualified botanist or agronomist as a consultant.

Step One in the program would be the sampling of the areas proposed for revegetation followed by detailed chemical and physical analyses of the samples. The chemical analysis should include all elements which can be deleterious or beneficial to plant growth, pH, and the soluble salts or compounds.

Step Two in the program would be greenhouse or growing room experimentation to determine the soil treatments that will be necessary and the varieties of vegetation which grow. Typically, a pH modifier such as lime or limestone is required and a combined nitrogen, potassium, phosphorous fertilizer such as 5-20-20. Occasionally a mulch is suggested to improve soil porosity and moisture and nutrient retention. In some instances the operators have been unable to get a vegetative response to any treatment.

Lime requirements vary with the acidity or acid generating potential of the tailings and can range from zero to 100 tons per acre. For some extreme situations injection with anhydrous ammonia can be attempted. Acidity which occasionally returns through transpiration, can be very difficult to control. Fertilizer requirements vary from 50 to

2,000 pounds per acre for the initial application with follow up requirements of from zero to 700 pounds per acre.

The eleven most common species used for the revegetation of tailings in Canada are as follows.

<u>Common Name</u>	<u>Latin Name</u>
Birdsfoot Trefoil	Lotus Corniculatus
Red Fescue	Festuca Rubia
Crested Wheatgrass	Agropyron Cristatum
Timothy	Phleum Pratense
Sweet Clover	Melilotus Officinalis
Red Clover	Trifolium Pratense
Kentucky Bluegrass	Poa Pratensis
Red Top	Agrostus Tenuis
Alfafa	Medicago Sativa
Bromegrass	Bromus Inermis
Perennial Rye	Lolium Perenne

Step Three in the program would be the large scale experimentation using the results of Step Two in plots at least one acre in size and encompassing all the disparate areas located in the Step One sampling.

The final step in the program would be the full scale implementation of revegetation on the areas to be covered with annual remedial work as required.

12. RECLAMATION

Reclamation is another concept which has become more prevalent in recent years. The intent is to return mining lands

after the cessation of mining activity to a semblance of the state of the land prior to mining. This might include the sealing of shafts, dismantling and removal of all buildings, equipment and foundations and revegetation or reforestation of all lands including waste dumps and tailing disposal areas.

The reclamation of the waste dumps and tailing disposal areas will present the most difficult problems to be faced primarily because of the undesirable effluents that will continue to emanate from them through precipitation and slimes consolidation. Prudence suggests that thorough initial project planning and concerned and future-oriented operation of the mine be combined to ameliorate the monumental task of reclamation after mine abandonment.

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Figure No. 2: Decant System (as per Campbell and Brawner)

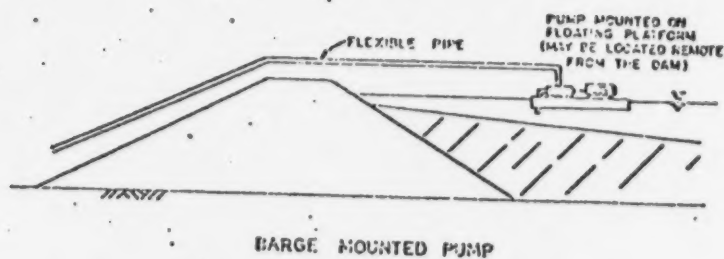
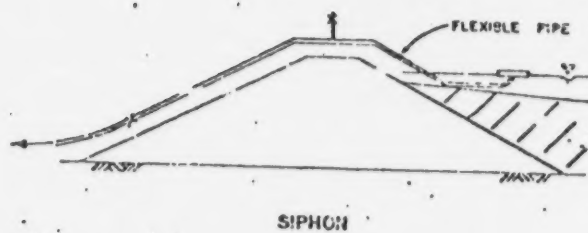
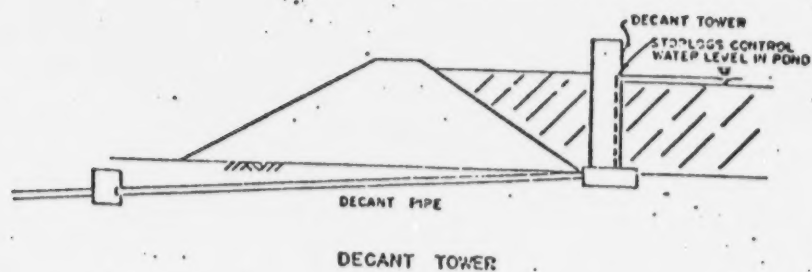
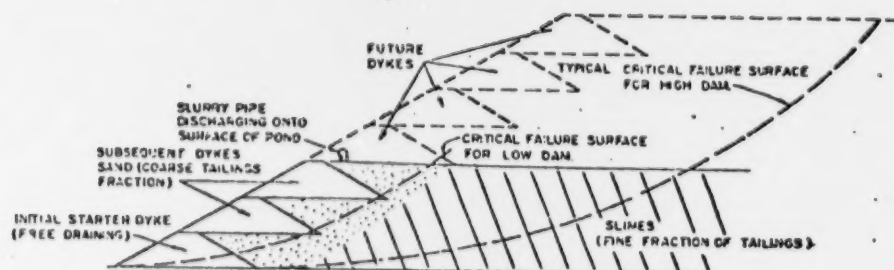
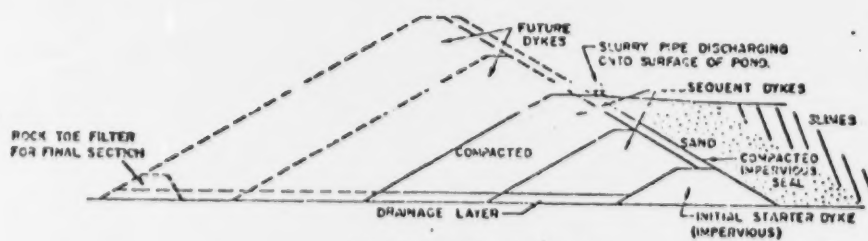


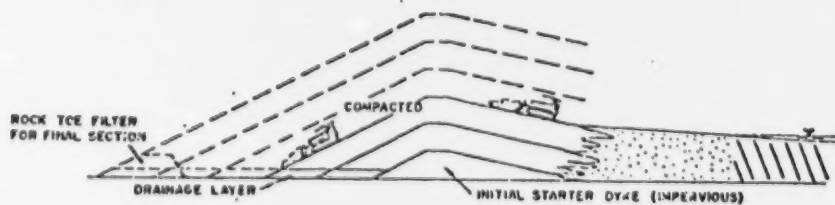
Figure No. 1: Standard Methods of Tailing Dam Construction
(as per Campbell and Brawner)



(a) UPSTREAM METHOD



(b) DOWNSTREAM METHOD



(c) CENTERLINE METHOD

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NORANDA SUBMISSION FOR CANMET TAILINGS REPORT

B.P. Wallace 24 January 1984

PART THREE - CURRENT TAILINGS MANAGEMENT PRACTICES

This section will consider the current practices employed for the impoundment of tailings. Current practice is defined herein to mean practice employed for the past fifteen to twenty years.

The industrial revolution began around the 1760's, but it was only in the 1960's that a broadly based concern for the integrity of the environment was brought to the attention of government. Government responded by passing enabling legislation to create agencies to provide regulations and guidelines to protect the environment but yet to attempt to avoid onerous penalties to the economy. In the past, tailings impoundment areas were selected, constructed and operated with criteria which included some of simplicity, expediency and frugality. Current practice reflects today's enlightened environmental standards and a significant expenditure in planning effort and in capital is made to ensure a new tailing impoundment area will provide the minimum practicable impact on the environment. Old existing facilities which are still in operation have modified the installations or operating practices to achieve an acceptable level of environmental conservation.

The differences which can be noted between past and current tailings impoundment selection, construction and operation may also become evident during reclamation and abandonment. While few, if any, modern tailings areas have

been reclaimed and abandoned, it may be that modern facilities prove to be more difficult to reclaim than old ones. This may seem initially as an unexpected result, but the greater attention paid in current practice to the minimization of seepage from an impoundment basin may hinder the dewatering and consolidation of the tailings.

Current practices for the impoundment of tailings will be examined under the three phases through which a mining development progresses, namely: pre-operation, operation and post-operation and abandonment.

3.1 Pre-Operation Phase

This phase includes the exploration for and the discovery of a mineral deposit, the definition of the deposit, the feasibility of an economic profit from the exploitation of the deposit, and if a satisfactory economic profit is projected, the detailed design and construction of the mining operation.

The pre-operational phase is seldom less than four years in duration and can often exceed double this time period. Following the discovery, the exploration department usually attempts to acquire additional land in the vicinity in order to provide improved flexibility in siting the surface administrative and processing buildings and the tailing impoundment facilities. As the definition drilling of the deposit proceeds with encouraging results, some background environmental records may be collected of

such basic parameters as evaporation, precipitation, temperature and stream flows.

Commencing at a time when definition drilling is about 50% complete, metallurgical test work is begun to determine the amenability of the ore to the various extraction methods to develop a process flowsheet. Initially the metallurgical test program is directed to the determination of a single most efficient, effective and profitable flowsheet for all ore types located within the deposit. When this flowsheet is known, the possible constraints from the issues of occupational health and the environmental conservation are investigated in order to develop an optimum flowsheet, to estimate the quantity of water which may be recycled and indicate the effect that recycle may have on the process and to assess the quality of the tailings and the potential areas of concern for the environment from the impoundment and storage of the tailings.

The quality of the tailings with respect to their potential to impact on the environment is primarily dependent upon the minerology of the host and gangue minerals and the quantities of deleterious elements present and secondarily upon the process flowsheet including whether hydraulic backfill is produced for the mine. The presence of iron sulphides in the tailings can suggest the potential for acid generation particularly if the neutralizing capacity of the other gangue minerals is low.

The B.C. Research Foundation has developed a laboratory methodology to provide an estimate of the potential for acid generation from mineral samples. A common practice is to submit a suite of samples representative of mill tailings prepared during the metallurgical test program and of mine waste for an assessment of the acid generation potential for these products during the early stages of the feasibility study.

The initiation of the feasibility study implies that a mineral deposit of sufficient size and grade has been discovered and that the minerals of economic interest appear to be satisfactorily extractable at a profit. The purpose of the study is to investigate all aspects of the exploitation of the deposit and to formulate an effective conceptual plan for the development. From the plan, reliable capital and operating costs can be estimated, the metal markets assessed and the likely profitability of the venture can be calculated with reasonable confidence.

The search for a suitable tailing impoundment site is intensified and usually concluded during the feasibility study. Some of the preferred criteria considered in the selection process are:

1. sufficient capacity for all tailings produced.
2. within 2 km of the process plant.
3. at a lower elevation than the process plant.
4. minimum height and length of dam.

5. relatively impermeable base.
6. minimum catchment area.
7. minimum groundwater flow.
8. not in an existing lake or water body.
9. satisfactory subsurface dam foundation materials.
10. local availability of dam construction materials.
11. not separated from the process plant by either a valley or a ridge.
12. not visually intrusive to the general public.
13. not as a source of dust to impact upon a highway or a community.
14. provide sufficient area and distance downstream of the dam to allow for adequate seepage interception and collection.

The search for the ideal impoundment site begins with the scrutiny of aerial photographs and expanded scale topographic maps. Seldom is the ideal site located and usually the search determines several sites which appear to meet some, but not all, of the preferred criteria.

Reconnaissance by helicopter can occasionally eliminate some of the preliminary sites, and perhaps locate an additional one not previously noted. However, inspection on foot of each potential site is mandatory for an adequate ranking of each site against the selection criteria dependent on visual data.

Engineering calculations of dam height against impoundment volume and quantity takeoffs for dam construction materials at various stages in the elevation of the dam to its ultimate height can be made. At this time, each remaining impoundment site can be rated against all the selection criteria, except those requiring subsurface and geotechnical investigations. The most highly ranked site or at most the two best sites can then be selected to the necessary geotechnical evolutions which would include boreholes along the axis of the dam, test pits, the installation of piezometers and the concomittant laboratory testing.

Eventually, one site will emerge which best meets the selection criteria and as each process plant site and tailing impoundment site is a unique pair it represents an optimum balance between capital cost, operating cost functionality and a preserver of the integrity of the environment. The selection of the impoundment site cannot address directly the minimization of acid generation because that quality of the tailings is a characteristic of the tailings and thus is independent of site selection. A site which offers a minimum catchment area and minimum groundwater flow and adequate room for the interception and collection of seepages best reflects the specific concerns related to acid generation in the tailings.

The site selection criteria did not include specific references to reclamation because the means to reclaim and finally abandon a modern tailing impoundment area are not known. The preferred long term solution to reclamation would seem to include dewatering of the tailing mass and covering of the impoundment area such that the continual weathering of the dam will not decades or centuries hence rupture and release a catastrophic flow of slurry to the environment. However, the site selection criterion requiring a relatively impermeable base for the impoundment area will retard the dewatering process although the minimization of the catchment area will at least reduce the amount of water entering the system.

The means to reclaim a tailing impoundment site and the period of time required for reclamation are not known. However, it is recognized that capital expenditures will be required over some period of years and that operating costs of seepage treatment plants or other facilities may be required for some longer period of time. The economic analysis contained within the feasibility study usually allows for these guestimated expenses.

The detailed design of the dam is primarily directed towards ensuring the structural integrity and impermeability of the completed facility. A concession made in consideration of the acid generation potential of a sulphide tailings to dam design would be to construct the dam only of borrow material and not from tailings.

3.2 Operations Phase *

This phase commences with the initiation of production mining and concludes with the final termination of mining activities. It would also include periods of suspension of mining due to low metal prices which make the operation uneconomic.

The operator places tailings within the impoundment area according to the manner intended by the designers and to the terms of the operating permit received from the regulatory agency. Distribution of the tailings is important for the most effective utilization of the available storage volume, for augmenting the structural integrity of the dam and for effective water management.

The operator should discharge tailings (or slimes if the sand fractions have been removed for hydraulic backfill or for dam building) from the distribution line laid along the upstream crest of the dam in order to build a beach of the coarser size fractions and allow the finer fractions to flow to the ponding area. The steeper slope at which the sands will deposit will keep the pond away from the dam and provide a lower phreatic level through the structure. The sand beach can provide additional stability to the dam and can provide a suitable material for raising the dam if this method was incorporated into the design of the structure. Raising of the dam must be scheduled in order that there is never an opportunity for the structure to overtop. No dam

* The practises described apply only to recent operations.

should ever have less than two full years of storage capacity.

Distribution of the tailings within the impoundment area is necessary to control the location of the water pond no matter whether a stationary decant tower is employed or a floating pumphouse is used to remove the supernatant water from the pond for recycle or discard.

Monitoring programs will be concerned with the quality and quantity of water in the tailing pond, water discarded, intercepted seepage water and the quality of water more remotely located from the impoundment area as evidence of the effectiveness of the impoundment system to contain impurities from the environment. The programs will be continued throughout the operations phase but the extent of the monitoring may change with time. If the monitoring results are stable and indicate a negligible impact on the environment, the program would be reduced accordingly. However, if problems arose or if an environmental impact were determined, further monitoring would be needed and remedial efforts developed.

3.3 Abandonment Phase

This phase commences with the final termination of mining activities and continues until the reclaimed facilities can be abandoned.

The objectives of reclamation should be to return mining lands after the cessation of mining to a semblance

of the state of land prior to mining and in a state which poses no threat to the environment and which requires no further care and attention by the mining company or others. However, how to achieve this utopian condition with a tailing impoundment area built and operated according to current practice has not been demonstrated.

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Kidd Creek Mines Ltd.

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(416) 869-1200

April 6, 1983

Mr. E.G. Joe,
Senior Industrial
Research Officer,
Mineral Sciences Laboratories,
555 Booth Street,
Ottawa, Ontario
K1A 0G1

Dear Ed,

RE: TAILINGS RESEARCH

Thank you for your letter concerning CANMET's proposal to coordinate a study on long-term management of sulphide-bearing mill tailings. Kidd Creek, as a major operating company in Canada would be very pleased to participate in a study of this nature.

A considerable amount of research and development work on the acid producing properties of sulphide tailings and their subsequent treatment has been completed. A Federal Government task force in the mid 1970's developed effluent treatment guidelines together with the necessary back-up information. This literature should be revised and brought up to date.

To ensure the comprehensive program is completed, there are four major areas to be addressed:

- 1) Design and installation of sulphide tailings disposal areas.
- 2) Operation and monitoring of active tailings disposal sites.
- 3) Reclamation of active and old tailings disposal sites.
- 4) The continued maintenance of reclaimed tailings disposal sites.



These areas of interest cannot be addressed without a framework of Government legislation both Federal and Provincial, both existing and proposed, on which to design and to assess the effectiveness of any research program. As discussed during the meeting in Ottawa, a survey of legislation pertaining to tailings disposal sites the ownership of such sites after reclamation and anticipated future effluent requirements from these sites required on a Canada wide basis.

In conjunction with the survey on legislative requirements a survey of present tailings disposal practice in the industry should be undertaken. Hopefully it could be undertaken in such a manner as to indicate the problem areas as well as the successes achieved. Using the anticipated future requirements and comparing this to existing practice, and with the addition of known problem areas a complete overview of the situation can be achieved.

One of the areas that has not been considered in any detail is that of reclamation and continued maintenance of tailings areas. A number of companies have designed a system with this in mind but the actual details of the reclamation have been left until closer to the finishing date of the area.

I trust that this overview will provide input to your formulation of a program for tailings research. I am personally most interested in the project. Kidd Creek Mines will support any initiatives in this direction to ensure that the highest practical environmental standards are achieved in its operations.

TAILINGS DISPOSAL PRACTICE AT KIDD CREEK MINES

The Kidd Creek Mine located in the City of Timmins, Ontario uses the thickened tailings concept of tailings disposal. All waste material from the process is pumped to the tailings area, from where the effluent is neutralized and treated for heavy metals removal and recycled to the milling process.

The tailings disposal area consists of an area of 1200 hectares, enclosed by dykes of imported fill. Tailings from the milling process is pumped 3 km to a tailings thickener where it is thickened to 65% solids. Thickener underflow is pumped to the spigot area where tailings is discharged into the centre of the 1200 hectare

area. Solids build up at the centre of the area forming a cone shaped deposit of tailings, with the spigot area forming the apex of the cone.

Effluent from the spigot area and the tailings thickener overflow flow around the perimeter of the tailings area to two holding ponds, shown in the attached diagram as ponds "A" and "C". Overflow from these ponds is neutralized by the addition of milk of lime to a pH of 10.5, and is aged in pond D to allow heavy metal precipitates, principally zinc, to settle out. Residence time in the pond averages 48 hours but considerable short circuiting occurs. Approximately 60% of the neutralized effluent at pH between 7.5 and 8.5 is recycled to the milling process while the remainder of the effluent is discharged to the Porcupine River. Control of heavy metals content is very good with the zinc content of the effluent varying from 0.1-0.2 parts per million except in Spring and Fall when the heavy metal content increases to the 0.5-0.8 parts per million range for a short period of time.

Some of the operating problems are:

- 1) control of the large volumes of water and its treatment during the spring breakup;
- 2) the relatively poor mixing of lime during the neutralization process, leading to excessive lime addition. Also the cold water temperatures do not help its solubility;
- 3) automatic control of pH if the discharge is difficult to achieve. Better sensors are required;
- 4) short circuiting of effluent in the aging pond;
- 5) coating of the recycle water lines with a gelatinous type of material during winter. This dissolves again when the water gets warmer.

Problems still to be resolved include:

- 1) recovery or disposal of heavy metal precipitates upon the aging pond;
- 2) can the tailings cone be re-vegetated successfully;

E.G. Joe

-4-

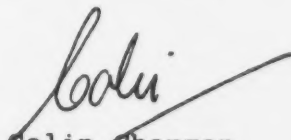
April 5, 1983

- 3) will neutralization of the run off from the revegetated tailings area always be required;
- 4) the tailings area is relatively large. What is the most cost effective way of reclaiming the area;
- 5) the effect of ice coverage on the tailings area and aging pond and its effect on the discharged effluent quality.

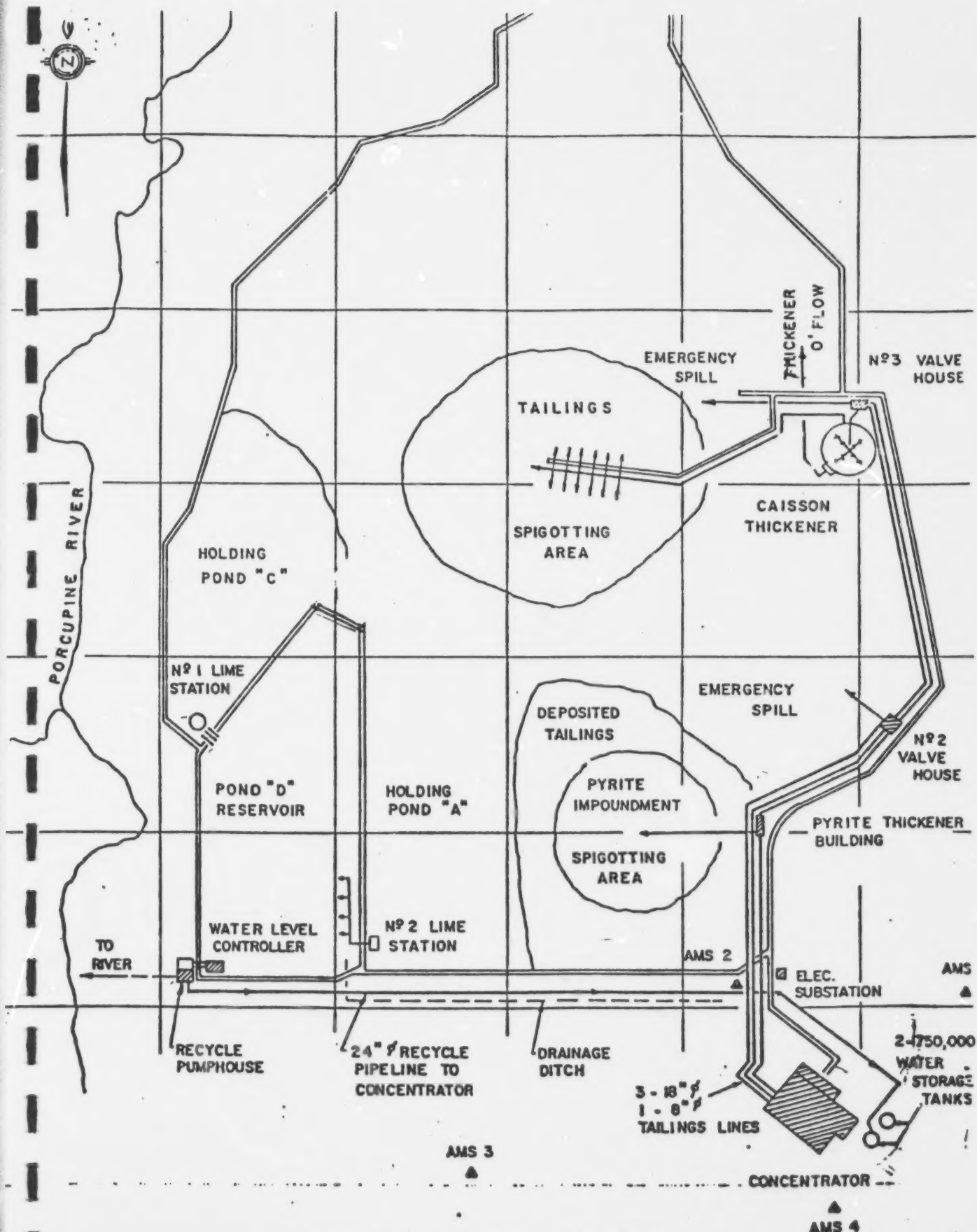
This is an outline of our present tailings impoundment procedure. To the end of 1982 41.9 million tonnes of tailings have been disposed into the area, and an additional 3.1 million tonnes of pyrite concentrate has been stock-piled separately. An estimate of the remaining life for the impoundment area is 40 years by which time 180 million tonnes of material will have been impounded. Volumes of effluent discharged from the tailings area to the environment varies from 200 cubic metres per minute during spring run off to more typically averaging 25 cubic metres per minute during the remainder of the year.

Trusting that this is the information you require for starting your study, I am,

Yours truly,


Colin Chapman
Chief Metallurgist
Kidd Creek Mines Ltd.

CC:db



TAILINGS DISPOSAL SYSTEM

16



HUDSON BAY MINING AND SMELTING CO., LIMITED

FLIN FLON MANITOBA

RBA 1N9

APRIL 20, 1983

ENERGY, MINES AND RESOURCES CANADA
RESEARCH AND TECHNOLOGY
CANADA CENTRE FOR MINERAL AND
ENERGY TECHNOLOGY
555 BOOTH STREET
OTTAWA, ONTARIO
K1A 0G1

ATTENTION: E.G. JOE - SENIOR INDUSTRIAL RESEARCH OFFICER
MINERAL SCIENCES LABORATORIES

DEAR MR. JOE:

YOUR LETTER OF FEBRUARY 9, 1983 TO MR. HILLIER WAS PASSED ON TO MYSELF FOR REPLY. MY DEPARTMENT IS RESPONSIBLE FOR TAILINGS DISPOSAL AND TAILINGS POND DEVELOPMENT FOR THE FLIN FLON/SNOW LAKE AREAS AND AS SUCH WOULD BE YOUR CONTACT FOR THIS PROPOSED TAILINGS MANAGEMENT STUDY.

WE WOULD CERTAINLY BE INTERESTED IN PARTICIPATING IN A STUDY OF THE LONG TERM MANAGEMENT OF SULFIDE-BEARING MILL TAILINGS AND FEEL POSITIVE CONTRIBUTIONS CAN BE MADE BY HUSBAY TO THE PROGRAM.

AS YOU REQUESTED, ATTACHED IS A BRIEF SUMMARY OF HUSBAY TAILINGS DISPOSAL/STORAGE PRACTICE AT BOTH THE FLIN FLON AND ANDERSON LAKE OPERATIONS. THE FLIN FLON SYSTEM UTILIZES FIXED PIPE DISCHARGE AND LAND DISPOSAL WHILE ANDERSON LAKE PRACTICES UNDERWATER DISCHARGE INTO A SHALLOW LAKE VIA MOVEABLE FLOATING PIPELINE. THE ANDERSON LAKE DESIGN WAS BASED ON EARLIER SUCCESS OF LONG-TERM TAILINGS STORAGE AT A LOCAL FLIN FLON AREA MINE KNOWN AS MANDY MINE. A COPY OF THE CASE HISTORY REPORT WHICH APPEARED IN RECLAMATION REVIEW, VOL. 1 IN 1978 IS ATTACHED FOR YOUR INFORMATION.

I MAY BE CONTACTED AT (204)687-5212 AND LOOK FORWARD TO HEARING FROM YOU IN THE NEAR FUTURE.



R.V. TYPLISKI, P.ENG.
SUPERVISOR ENVIRONMENTAL CONTROL

:JM

CC: WWF/JAH/RHC/SPW/RVT

INTER-OFFICE CORRESPONDENCE
HUDSON BAY MINING AND SMELTING CO., LIMITED

Date APRIL 20, 1983

To R.V. TYPLISKI At
From R.H. CORDEN At
Subject TAILINGS RESEARCH PROJECT - CANMET

IN RESPONSE TO YOUR REQUEST FOR A BRIEF SUMMARY OF HUDSON BAY'S CURRENT TAILINGS MANAGEMENT PRACTICE AT THE FLIN FLON AND SNOW LAKE OPERATIONS, I SUBMIT THE FOLLOWING:

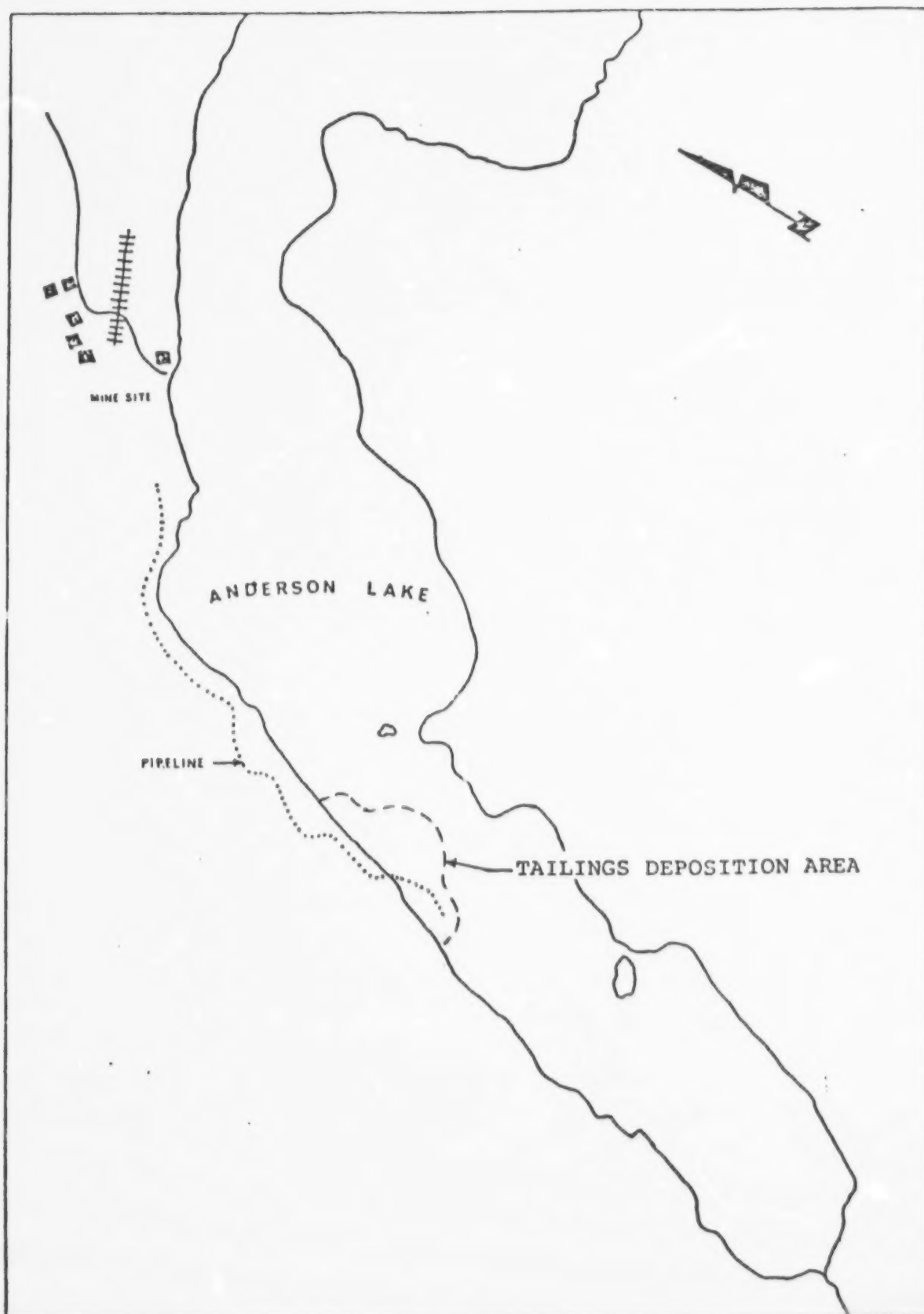
FLIN FLON TAILINGS SYSTEM

IN OPERATION SINCE 1930, THE FLIN FLON TAILINGS SYSTEM CONTAINS APPROXIMATELY 66 MILLION TONS OF TAILINGS AND COVERS AN AREA OF 650 ACRES. TAILINGS FROM THE CONCENTRATOR ARE SLURRIED WITH WATER INTO A 16-20% SOLIDS MIXTURE AND PUMPED TO THE TAILINGS POND WHERE THEY ARE DISCHARGED BY THE "END OF PIPE" METHOD. APPROXIMATELY 900 000 TONS OF TAILINGS ARE DISCHARGED TO THE STORAGE AREA EACH YEAR.

ONCE IN THE TAILINGS POND, SEE ATTACHMENT 1 & 2, THE TAILINGS UNDERGO A PROCESS OF PHYSICAL AND CHEMICAL TREATMENT PRIOR TO FINAL EFFLUENT RELEASE INTO THE ENVIRONMENT. PHYSICAL TREATMENT OR SUSPENDED SOLIDS REMOVAL IS COMPLETED IN THE PRIMARY AND SECONDARY PONDS WHILE CHEMICAL TREATMENT IS COMPLETED IN THE CLARIFICATION POND VIA THE ADDITION OF LIME TO REMOVE HEAVY METALS. THE PHYSICAL AND CHEMICAL PROPERTIES OF THE TAILINGS ARE LISTED IN ATTACHMENT 3. THE TAILINGS SYSTEM HAS OVER THE PAST SEVERAL YEARS BEEN APPROXIMATELY 99% EFFICIENT WITH RESPECT TO REMOVING METAL/SOLIDS CONTAMINANT LOADING FROM THE FINAL EFFLUENT.

ANDERSON LAKE TAILINGS SYSTEM

IN OPERATION SINCE 1979, THE ANDERSON LAKE TAILINGS SYSTEM CONTAINS 1.61 MILLION TONS OF TAILINGS, THE LAKE SURFACE AREA IS APPROXIMATELY 900 ACRES. DURING INITIAL OPERATION 1979 THROUGH 1981 THE METHOD OF DISPOSAL WAS THE "END OF PIPE" METHOD, HOWEVER, SINCE DECEMBER 1981 A MOBILE FLOATING PIPELINE HAS BEEN UTILIZED TO DISTRIBUTE TAILINGS THROUGHOUT THE TAILINGS STORAGE AREA, SEE ATTACHMENTS 4 & 5. THE PRESENT TAILINGS DISCHARGE RATE IS ABOUT 550 000 TONS PER YEAR. THE ANDERSON LAKE TAILINGS SYSTEM UTILIZES UNDERWATER TAILINGS STORAGE AIMED AT PROVIDING A STABLE ENVIRONMENT FOR LONG TERM TAILINGS STORAGE. THE CONCEPT IS BASED UPON EARLIER HUDBAY EXPERIENCE WITH UNDERWATER TAILINGS STORAGE AT AN OPERATION KNOWN AS MANDY MINE. "A CASE HISTORY OF NATURAL UNDERWATER REVEGETATION: MANDY MINE HIGH SULFIDE TAILINGS" BY R. HAMILTON AND W.W. FRASER, AND PUBLISHED IN THE RECLAMATION REVIEW, VOL. 1, PP 61-65, 1978, IS INCLUDED AS ATTACHMENT 6.

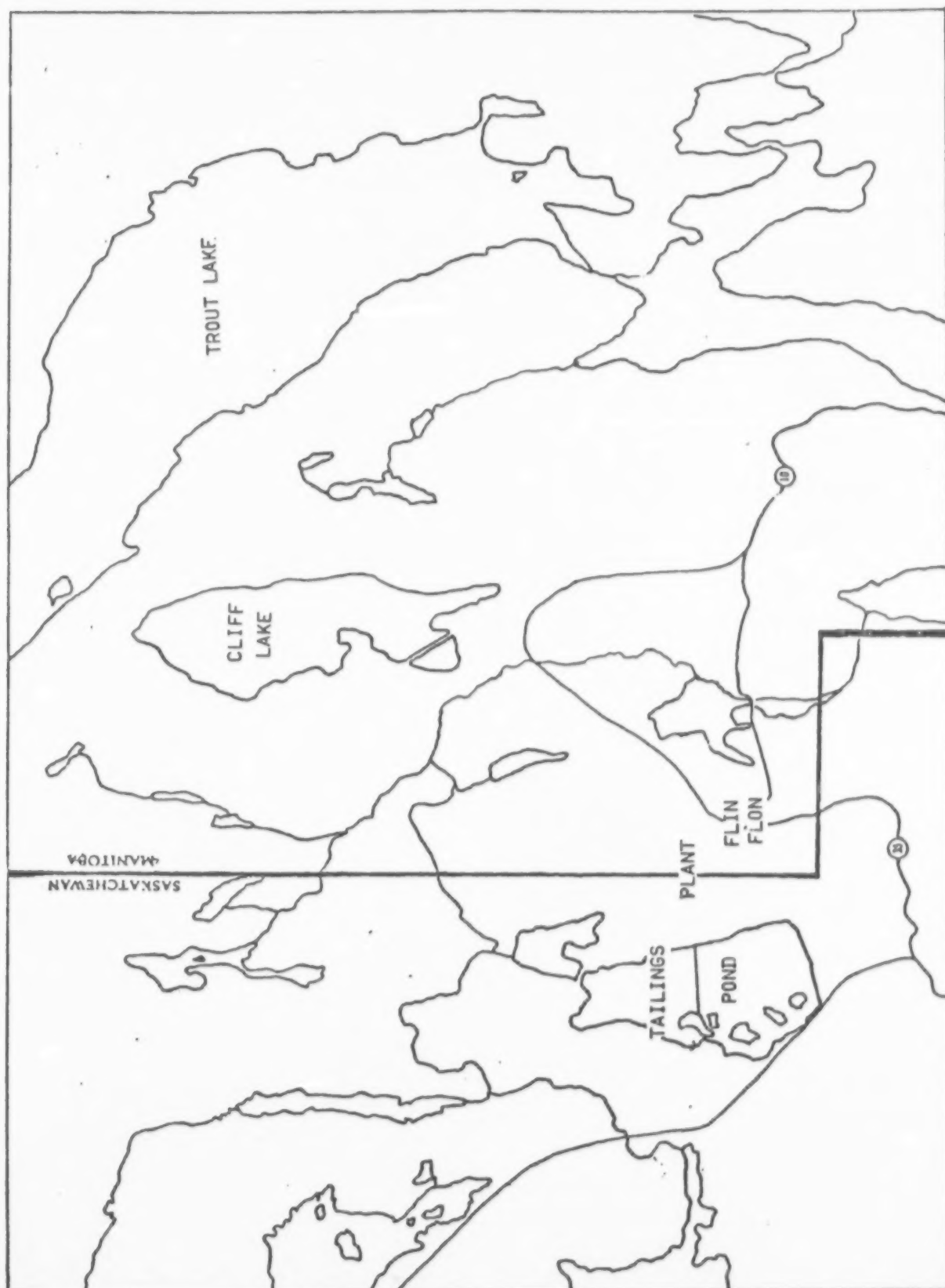


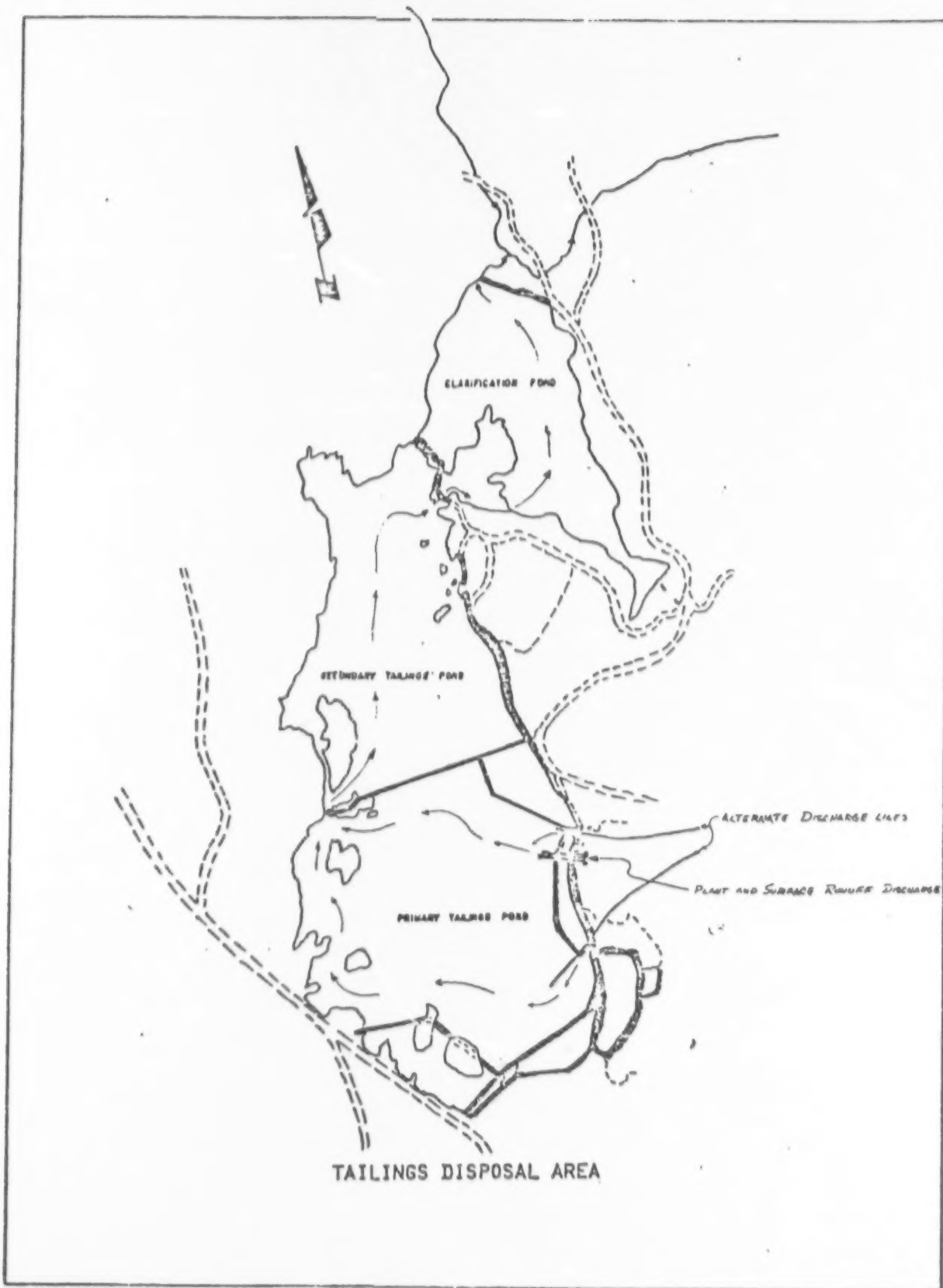
FURTHER ON THE ANDERSON LAKE TAILINGS SYSTEM, 75% OF ALL WATER DISCHARGED INTO THE LAKE IS RECLAIMED FOR USE IN THE CONCENTRATOR. DISCHARGE FROM THE LAKE IS PERIODIC, GENERALLY FOR HANDLING SURFACE RUNOFF IN THE SPRING AND WINTER STORAGE IN THE FALL. WITH RESPECT TO THE EFFICIENCY OF THE SYSTEM, WATER QUALITY SURVEYS CONDUCTED SINCE START-UP IN 1979 HAVE RECORDED LITTLE CHANGE IN VALUES OF ZINC, COPPER, PH, SULFATES, SUSPENDED SOLIDS AND TURBIDITY WITHIN THE LAKE.



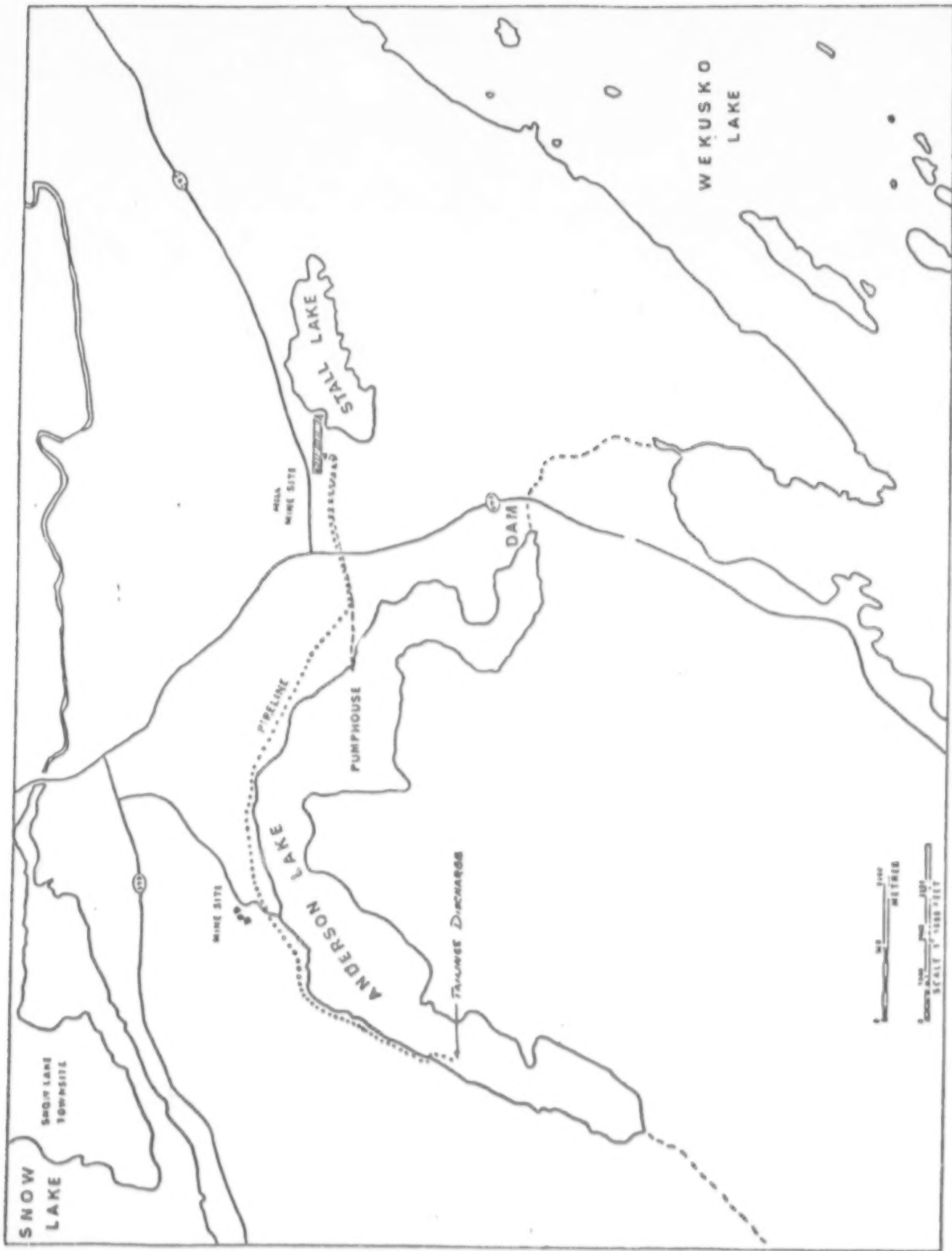
R.H. CORDEN

:JM





COMMODITY	WASTE TYPE	CONTACT	LOCATION	MINE
COPPER ZINC	TAILINGS	Hudson Bay Mining & Smelting Co., Flin Flon, Manitoba. R2A 1N9	Flin Flon, on Manitoba - Saskatchewan border.	HUDSON BAY MINING & SMELTING
CLIMATE			OREBODY GEOLOGY	
ANNUAL MEAN TEMPERATURE °C -2.2- +4.6			Metamorphic volcanic and sedimentary rocks. Ore located in quartz porphyry.	
GROWING DEGREE DAYS 1120 - 1425			Ore - Massive sulphides containing chalcopyrite, pyrite and sphalerite with some disseminated chloride schist.	
FROST FREE PERIOD start length in days: 120				
GROWING SEASON start length in days Mid May 146				
PRECIPITATION annual cm 47.6				
growing season cm 23.1				
DISPOSAL METHOD & SIZE			WASTE MINERALOGY	
253 ha; area retained by natural and man-made dams. Decant drains over a concrete control structure.			Pyrite, pyrrhotite and quartz.	
PHYSICAL PROPERTIES			VEGETATION & COMMENTS	
MEAN RANGE			Regional: Coniferous forest.	
PARTICLE SIZE % <2mm 70 49 - 94			Volunteer: None.	
DISTRIBUTION % sand 47 23 - 82			Introduced: Oats, barley, brome grass, quack grass, perennial rye grass, Kentucky blue grass, red fescue.	
% silt 5 1 - 12			Comments: Reclamation attempts commenced in 1971.	
% clay 5 1 - 12			2 ha experimental plot.	
MOISTURE 0.1 bar % 26 25 - 28			Mine staff studied the wastes and conducted test work without adequate success at maintaining a cover. They are looking at alternative methods of reclamation.	
RETENTION 0.3 bar % 17 16 - 18				
15 bar % 7 6 - 9				
AVAILABLE WATER %				
STORAGE CAPACITY				
BULK DENSITY g/cm³ 1.7 1.4 - 1.84				
PARTICLE DENSITY g/cm³ 3.35 3.15 - 3.48				
CHEMICAL PROPERTIES				
MEAN RANGE				
pH water 6.5 4.9 - 7.4				
CaCl				
CATION EXCHANGE CAPACITY meq/100g 24.1 14.1 - 46.5				
ORGANIC MATTER % 0.4 0.3 - 0.5				
ELECTRICAL CONDUCTIVITY mhos/cm				
SOLUBLE SALTS ppm 8184 3984 - 16,368				
AVAILABLE ELEMENTS P ppm 0.5 0.5 - 0.8				
K ppm				
Ca ppm				
Mg ppm				
TOTAL ANALYSIS N % 20 16.5 - 26.5				
S % 24 23.1 - 24.8				
Fe % 3.3 2.1 - 4.2				
Al % 2 1.2 - 2.4				
Ca % 1.9 1.07 - 2.8				
Mg % 0.37 0.24 - 0.43				
Na % 0.6 0.38 - 0.8				
K % 0.08 0.07 - 0.09				
Mn % 4.7				
Si ppm 5000				
Co ppm				
SOURCE			Hudson Bay Mining & Smelting Co Flin Flon, Manitoba Date: 1975	



A Case History of Natural Underwater Revegetation: Mandy Mine High Sulfide Tailings

R. HAMILTON and W. W. FRASER

*Hudson Bay Mining and Smelting Company Limited
Flin Flon, Manitoba, Canada*

The results of underwater impoundment of high-sulfur base metal tailings with respect to its effect on aesthetics, erosion, and water quality has been determined by a study of the tailings area associated with the Mandy Mine in the Flin Flon, Manitoba, Canada area.

After 32 years of underwater impoundment the high iron and sulfur content material has oxidized very little. With no expenditures on rehabilitation or site maintenance, water quality is good and aquatic animal and insect life has moved into the tailings area. Vegetation has colonized the area and has produced a mat of organic matter covering the entire surface of the tailings material.

Les résultats de l'accumulation, sous l'eau, de résidus de métaux de base, avec un haut contenu de soufre en relation avec la beauté du paysage, l'érosion, la qualité de l'eau, ont été déterminés par l'étude des résidus dans la zone de Mandy Mine, située dans la ville de Flin Flon, Manitoba, Canada.

Après 32 ans d'accumulation, sous l'eau, le haut contenu de fer et soufre des matériaux, est très peu oxydé. Sans aucune dépense pour la réhabilitation ou l'entretien du site, la qualité de l'eau est bonne, les animaux aquatiques et les insectes sont revenus dans la dite zone des résidus. La végétation a colonisé cette zone et a produit un tapis de matière organique qui couvre la surface entière des résidus de la mine.

INTRODUCTION

MOST of the rehabilitation work to date on tailings material has been concentrated on establishment of a vegetation cover. This method appears, at present, the best for a quality rehabilitation scheme. The success of such a scheme, however, is affected by many adverse factors and cost and maintenance are major considerations.

Some interest has been expressed concerning alternate methods of rehabilitating tailings material. Ideally, any method used should provide improvement in three ways: aesthetics, erosion control and water quality control. One method that would appear to meet the requirements, and also exhibits low cost and maintenance, is deposition of tailings material underwater. In the Flin Flon area of Manitoba the Mandy Mine site is an example of such underwater deposition.

The problem with most base-metal mine tailings is the high sulfur content. In these materials, acid production is the major detrimental factor which must be controlled before a rehabilitation scheme is effective. The reaction involved in acid production is the well-known oxidation of sulfidic material to form sulfuric acid, hydrous iron oxides and related sulfate salts [1]. Oxygen and water are required for completion of the reaction; if oxygen is unavailable, the sulfidic materials should remain in an unaltered state with no decrease in pH or increase in soluble constituents.

Theoretically, underwater deposition should exclude all oxygen from the tailings mass. In actual fact, however, there is always some dissolved oxygen present in water. If seepage is allowed, oxygen can be carried into the material. If the seepage can be restricted, only the material

in contact with the overlying water will be affected by oxygenated water. As a result, the amount of oxidation that will occur should be minimal and only at the surface of the tailings mass. The water quality should be excellent and aquatic vegetation and life should contain species that are pollution intolerant.

This report outlines an attempt made to determine what effects the Mandy Mine tailings have had on the environment in and around their area of deposition.

SITE DESCRIPTION

The Mandy Mine site was one of the first mineral claims to be worked in the Flin Flon, Manitoba, Canada, area. The ore vein, comprised of solid chalcopyrite averaging over 20% copper with significant amounts of gold and silver and surrounded by lower grade sulfides, was mined during the years 1917 to 1920, with the ore transported to Trail, British Columbia. In 1920, the richest veins were exhausted and the mine closed. The deposit was again mined between April, 1943 and December 1944, the ore was milled on site, and the tailings were deposited into a shallow, semi-confined lake adjacent to the property.

The now-abandoned Mandy Mine site is located on what used to be a peninsula in the N.W. arm of Schist Lake approximately five kilometres from the city of Flin Flon. At present there is a causeway between the tip of the peninsula and shore creating a small lake which includes the area in which the tailings are impounded. The level of this lake, Mandy Lake, is slightly above that of Schist Lake into which it drains. Mandy Lake receives drainage from Phantom Lake to the west, as well as spring water.

The majority of the tailings material has been underwater for 32 years, where it was placed in a fan-shaped deposit from a single launder. Some was spilled along the shore where it has remained. The deposited tailings have a gradual slope away from the shore ranging from 30 to 107 cm below water level. At the dropoff point the tailings give way to a black, soft sediment with a slightly septic odor.

Unfortunately, little data is available on the tailings as they were deposited, except that the sulfide tailings minerals were predominantly pyrite, sulfur content was in the 15-17 percent range and appreciable levels of zinc and copper remained in the material.

SITE INVESTIGATION

A program of investigation was conducted on

the tailings material, water and aquatic life during October, 1975 and August and October, 1976. Tailings samples and water samples from above the tailings were collected in 1975 with the remainder of the samples collected in 1976.

The tailings deposits were sampled in six locations, four underwater samples and two on shore. An Eckman Dredge and trowel were used for collection of samples. Samples were taken to a 15 cm depth, air dried and mixed thoroughly before analyzing.

Water samples were taken above each of the four underwater tailings sampling locations and from inlet and outlet streams of Mandy Lake. All water samples were collected in polyethylene bottles and assayed within 24 hours.

The aquatic life was observed and sampled in the area affected by the tailings mass for identification of genus and species. The tailings solids were analyzed for total aluminum; silica; iron and iron oxide [2]; total sulfide and sulfate sulfur [3]; and total copper, zinc, lead, cadmium, calcium and magnesium [4].

Soluble constituents were determined on 1:5 distilled water extractions of the material with analyses including soluble copper, zinc, lead, cadmium, iron, calcium, magnesium [4] and sulfates [5]. The pH was determined in a 1:1 distilled water—tailings material slurry and conductivity was determined on a saturated extract [2].

Analyses were also conducted on acid-production potential [6]; specific gravity, bulk density [2]; and percolation rate using a constant-head percolation column.

Water samples were analysed for pH, conductivity, sulfate [1] and total constituent [4]. The totals include both dissolved and suspended values in each water sample.

Average results, not intended to give an absolute picture of the material but rather an idea of the trends, are included for both underwater and shore samples; the complete results can be obtained from the Environmental Control and Process Technology Department, Hudson Bay Mining and Smelting Company Limited, Flin Flon, Manitoba.

Results obtained for the Mandy Mine tailings have been compared to values found in the Cuprus Mine tailings, a similar tailings mass exposed for approximately the same length of time. These Cuprus Mine tailings, 11 km south-east of Flin Flon, are approximately 22 years old and exposure to the elements has resulted in all the classic symptoms of oxidation processes. Three distinctly different materials presently exist: the top 15 cm of heavily oxidized material overlies a lateritic hardpan layer of 10-15 cm, while the material beneath the hardpan is essentially un-

oxidized. The average values for the top layer are used for comparison in this report.

RESULTS AND DISCUSSION

The factors generally associated with an exposed tailings area are sulfide oxidation, iron oxide formation, acid production, high soluble salt concentrations, low nutrients, hardpan and profile development, and erosion. All of these contribute in one way or another to undesirable aesthetics, poor water quality and material erosion.

The most desirable course for rehabilitation has been to establish a cover of vegetation. In general, however, this method has exhibited a high requirement for soil amendment, labour, machinery, maintenance, and expense. It is generally accepted that vegetation does improve the aesthetics and controls erosion; however, its affect on water quality is still not conclusive.

Underwater deposition of tailings material appears to be a viable alternate method. There is no requirement for amendments and very little requirement for labour, machinery and maintenance. Theoretically, it should result in improvement in aesthetics, water quality and erosion control. If the water level is maintained and seepage is restricted, there should be essentially no change in the material after it is deposited.

Table 1. Composition of Tailings from Mandy Mine and Cuprus Mine

Constituent (%)	Mandy Mine		Cuprus Mine Top Profile
	Underwater	Shore	
Total Iron	17.4	19.8	24.5
Iron (Fe_2O_3)	0.8	2.9	15.8
Total sulfur	15.5	15.8	6.6
Sulfide sulfur	15.4	15.5	2.7
Sulphate sulfur	0.03	0.30	3.9
Aluminium (Al_2O_3)	8.4	6.7	2.9
Silica (SiO_2)	35.7	37.7	27.7
Copper	0.91	2.70	0.19
Zinc	4.70	1.60	0.18
Lead	0.13	0.12	0.08
Cadmium	0.01	<0.01	<0.01
Calcium	1.04	0.51	2.87
Magnesium	1.75	1.03	0.54

Total Analyses

The values for total analyses (Table 1) indicate that there are differences in the chemical composition associated with different areas sampled. Some of these differences can be attributed to the original composition of the material and some to the chemical changes that have occurred.

Of significant interest in the total analyses are the iron, sulfur, aluminum oxide, and silicate. The original tailings material was composed mainly of iron-sulfur compounds with little iron oxide or sulfates. With oxidation, the iron-sulfide compounds would be converted to insoluble iron oxide and leachable sulfate and iron, as indicated by the top profile of the Cuprus material. With leaching of the iron and sulfate salts, the percentage of aluminum oxide and silicate will increase and the percentage of iron and sulfur will decrease; collection of slit by vegetation on the underwater tailings would be expected to result in an increase in aluminum and silicate values.

The underwater Mandy Mine tailings do not exhibit the same trends. It is apparent that very little of the iron has been converted to iron oxide, similarly with sulfide to sulfate. The more oxidized shore samples do exhibit higher values; however, even they are low, possibly because they are in close proximity to the lake and are periodically covered with water depending on lake level fluctuations.

It is apparent from the values that deposition underwater effectively retards the oxidation reaction.

Soluble Salts

It is evident from the data recorded in Table 1 that oxidation, while retarded, is not completely eliminated. One would therefore expect that some soluble salts would be present, with corresponding effects on the water quality, including a decrease in pH and an increase in conductivity corresponding to the solubility of heavy metals and sulfates.

The Cuprus tailings results are a good example of this. In Table 2, Cuprus Top Profile (oxidized) exhibits the lowest pH and a highest conductivity. The underwater and shore samples of Mandy tailings exhibit a similar trend, with the oxidized

Table 2. Soluble Constituents in a 1:5 Distilled Water Leach of Tailings from Mandy and Cuprus Mine

Constituent (mgm/kg tailings)	Mandy Mine		Cuprus Mine Top Profile
	Underwater	Shore	
Iron	0.9	84.3	8,530
Copper	0.25	6.23	797
Zinc	15.5	44	218
Lead	0.35	1.05	1.27
Cadmium	0.05	0.28	0.57
Calcium	145	2,590	2,360
Magnesium	18	121	577
Sulphate	240	7,340	35,400
pH	6.9	4.9	2.5
Conductivity (mmho/cm)	0.4	2.45	7.20

Table 3. Acid Generating Potential of Mandy Mine and Cuprus Mine Tailings

Parameter	Mandy Mine		Cuprus Mine Top Profile
	Underwater	Shore	
Original pH	6.7	4.4	2.5
Total sulfur (kg/tonne)	156	158	65
Acid production potential (kg/tonne)	475	484	201
Acid consuming ability (kg/tonne)	52	4	0
Net acid production (kg/tonne)	424	480	201

shore samples having a low pH and high conductivity. Both the pH (6.9) and the conductivity (0.44 mmho/cm) of the underwater samples are comparable to accepted water quality standards (Table 5), indicating that the material should contribute very little to a detrimental change in water quality: some contribution may be expected from the shore samples.

The low degree of oxidation and high pH of the Mandy underwater tailings sample govern the low amounts of constituent that have become soluble. Maintenance of this material underwater should control the rate at which the oxidation reaction is taking place; therefore, there should be no significant change in the pH of the material. If the material remains at its present pH, the amounts of constituent that will become soluble will be very small.

Acid Production Potential

All of the samples tested were net acid producers. The more oxidized Mandy Shore and Cuprus samples (Table 3) had very low acid consuming ability, while the underwater samples at Mandy still exhibit a substantial amount of acid consuming ability.

Indications are that if the underwater material is allowed to oxidize, this acid consuming ability would soon be used up. It is probable therefore, that very low acid generation has occurred in the underwater material.

Physical Characteristics

The data recorded in Table 4 indicates a considerably lower specific gravity and bulk density in the Cuprus material. In the Mandy material there is little difference between the specific gravities of the underwater and shore samples. The higher specific gravity for the oxidized shore sample probably reflects the differences in the chemical composition of the material (Table 1). A similar difference can be noted in the bulk den-

Table 4. Some Physical Properties of Mandy Mines and Cuprus Mine Tailings

Physical Property	Mandy Mine		Cuprus Mine Top Profile
	Underwater	Shore	
Specific gravity (gm/cc)	3.03	3.07	2.47
Bulk density (gm/cc)	1.57	1.76	1.29
Percolation (ml/min)	0.92	0.21	0.10

Table 5. Quality of Inlet and Outlet Water at Mandy Lake

Parameter	Sample Source		
	Inlet	Outlet	Above Tailings
pH	7.6	7.7	7.7
Conductivity (mmho/cm)	0.20	0.39	0.26
Copper (mg/L)	0.01	0.02	0.01
Zinc	0.14	0.13	0.20
Lead	0.01	0.01	0.01
Cadmium	0.01	0.01	0.01
Iron	0.11	0.23	0.05
Calcium	22.0	22.5	21.0
Magnesium	5.3	5.5	5.6
Sulphate	28.8	21.7	—

sity, but this could be influenced by the lack of compacting forces in the underwater sample.

The moisture percolation rates were low for the oxidized samples of Mandy and Cuprus materials. The fine particles of iron oxide material and high salt concentration would act to retard the flow, causing a build-up in the salt concentrations in the water and material. The underwater samples at Mandy have a high percolation rate, indicating a lack of finer particles and salts. If seepage were not restricted through the underwater material, the high percolation rate could lead to high oxidation rates.

Water Quality

Analysis showed, (Table 5), that both the inlet and outlet waters of Mandy Lake are similar in quality. The outlet water is higher in pH and does have higher contents of copper and iron but it contains less zinc and sulfate. Both the outlet and inlet samples are of acceptable water quality and it would be reasonable to assume that deleterious effects would be negligible.

In that samples of water taken from above the tailings are also of acceptable quality, the increase in constituents of the outlet waters would not appear attributable to the underwater tailings material. Surface run-off from the Mandy Mine area and another mine site in the vicinity, exposed tailings material and the presence of sulfide outcrops and underwater springs could account for the increases; however, these possible sources could not be sampled.

Vegetation Establishment

Vegetation has become established in the submerged tailings, but none on the tailings exposed to the atmosphere. Commonly occurring species are sedges (*Carex* spp.), riverweed (*Podostemum ceratophyllum* Michx.) and spike rush (*Eleocharis* spp.). A layer of decaying organic material, up to 2.5 cm thick underlies the standing vegetation and covers 90-95 percent of the shallow sloping tailings area. By comparison the vegetation occurring in lake areas away from the tailings deposit is composed primarily of cat-tails (*Typha latifolia* L.), yellow pond lily (*Nuphar variegatum* Engelm.), water smartweed (*Polygonum amphibium*), bullrushes (*Scirpus* spp.) and pondweeds (*Potamogeton* spp.).

Animal species occurred universally through non-affected and tailings areas and no distinction was determined between the two in terms of occurring species.

CONCLUSIONS

This investigation has shown that in the case of the Mandy Mine tailings, underwater deposi-

tion has resulted in an aesthetically acceptable environment, little if any detrimental effects on water quality in the area and an absence of surface erosion problems. Unlike other rehabilitation schemes for high sulfide materials, there has been no requirement for excessive capital expenditure and maintenance. The underwater material has revegetated naturally, a phenomenon which would not have occurred within a 32 year time frame if the tailings had been stored in surface impoundments.

It must be emphasized that the investigation deals only superficially with the Mandy Mine tailings. A more detailed study would be required from the time of actual deposition to the time of establishment of vegetation cover in order to determine effects on the ecosystem during the early years by the deposited tailings material. Before any deposition of this type is contemplated the tailings receiving area should be investigated with reference to maintenance of a constant water level, reduction of seepage, and control of the spread of the material to retard bottom smothering.

REFERENCES

1. Hawley, J. R., *The Problem of Acid Mine Drainage in the Province of Ontario*. Ministry of the Environment, Toronto, Ontario, (1972).
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6. Anon. *Measurement of Acid Producing Material*. Project 1499. British Columbia Research Foundation. Vancouver, British Columbia, (no date).
7. Hamilton, G. R., *Cuprus Mine Tailings Investigation*. Internal Report, Hudson Bay Mining and Smelting Company Ltd., Flin Flon, Manitoba, (1976).

REQ. NO. 3-9041

CONTRACT REPORT NO. OSQ 83-00117

APPENDICES

VOLUME TWO

EFFLUENT TREATMENT PRACTICES
AND RECLAMATION/REVEGETATION
PRACTICES

SULPHIDE TAILINGS MANAGEMENT STUDY

A Joint Project of

Monenco Limited, Cominco Limited, Inco Limited
and Noranda Research

May 1984

MICROMEDIA

MAR 15 1985

254 pp

Monenco Limited
500 Beaverbrook Court
Fredericton, New Brunswick
E3B 5X4

VOLUME TWO

C. CURRENT EFFLUENT TREATMENT PRACTICES

- C-17 MINE AND TAILINGS EFFLUENT TREATMENT SULLIVAN OPERATIONS
- C-18 TAILINGS DISPOSAL WATER MANAGEMENT - INCO'S COPPER CLIFF AND SHEBANDOWAN OPERATIONS
- C-19 TREATMENT OF ACID-MINE WATERS WITHIN THE NORANDA GROUP

D. CURRENT RECLAMATION/REVEGETATION PRACTICES

- D-20 RECLAMATION AT COMINCO'S SULLIVAN MINING OPERATIONS
- D-21 RECLAMATION AT COMINCO'S BENSON LAKE OPERATION
- D-22 RECLAMATION AT COMINCO'S CON MINE
- D-23 RECLAMATION AT COMINCO'S BLUEBELL AND PINCHI LAKE MINES
- D-24 REVEGETATION PROGRAM ON INCO LIMITED'S TAILINGS AREAS
- D-25 RECLAMATION AT NORANDA'S OPERATIONS
- D-26 RECLAMATION AT FALCONBRIDGE OPERATIONS
- D-27 CANADIAN RECLAMATION ASSOCIATION, PROCEEDING OF THE THIRD ANNUAL MEETING, 1978

C

17

Tailings Management Study - Part IV Information

Sullivan Operations, Kimberley, B.C.

4.1 Acid Formation

The Sullivan is one of the few major Western Canadian orebodies which may be classed as "acidic" in nature. That is, the primary economic minerals, galena and marmatite, are enclosed in a siliceous host rock with abundant pyrrhotite, but with little or no accompanying gangue minerals such as calcite and dolomite. The unavoidable consequences of mining such an ore and impounding its tailings are that contact with air and water generates acidic drainages which contain various soluble metals originally present as sulphide minerals.

The mine drainage is a combination of surface water that has infiltrated through the orebody and that pumped in for drilling. Retention in the mine's massive hydrologic system is such that the full impact of high surface infiltration rates requires about one week to be reflected in drainage volumes. Periods of high flow and high metals concentrations often occur simultaneously during, for example, the spring freshet due to a "flushing" of sulphate salts accumulated in rock fractures. It is interesting to note that there are areas of the mine where stalactites develop composed of crystalline metal sulphate salts.

The average annual mine drainage rate is about 3,000 L/min. in a range of 1,200 -10,000 L/min. This flow is conveyed to the iron tailings pond.

The impact of precipitation and runoff is even more severe from the concentrator's iron and siliceous tailings ponds which presently cover areas of 230 and 140 hectares, respectively. Rapid snow melt during warm spring days and heavy rains cause extremely high rates of water accumulation that can change, virtually on an hourly basis. These flows are now managed behind a robust dyke system whereas previously there was little or no attenuation of decant rates. Peak instantaneous flows in the iron pond have reached 55,000 L/min. but 6,000 L/min. is a typical annual average. Corresponding decant accumulation rates in the smaller siliceous tailings pond are 23,000 L/min. and 4,000 L/min., respectively.

Since the siliceous tailings are largely inert gangue minerals, decant from this pond usually contains only minor contamination and the ph is normally about 7.0. However, on rare occasions, soluble Mn and Fe concentrations have reached 15 and 75 mg/L. Current monitoring data on the individual mine drainage and iron tailings water are not available since these flows have been combined in the iron pond since 1979. However, information from previous years is illustrative of the degree

of reactivity in the ore and high sulphide tailings. Ranges of soluble metals concentrations and other parameters which have been experienced are presented in the following table:

<u>Parameter</u>	<u>Mine Drainage, mg/L</u>	<u>Iron Tailings Water mg/L</u>
Fe	200-1,000	300-2,500
Mg	300-800	50-100
Zn	30-200	10-50
Al	35-150	--
Pb	2-5	2-8
Mn	20-75	5-30
Suspended Solids	200-900	25-100
pH	2.5-4.0	3-5.0
Temperature, °C	8-12	0-15

Oxidation reactions generate basically the same soluble metals in both drainages although in different proportions but Fe is dominant in both systems. Acidity is generally higher in the mine drainage and its attack on magnesium aluminum silicate gangue minerals is made evident by the relatively high aluminum and magnesium concentrations in this flow. The high Fe concentrations in relation to the other heavy metals is clearly a reflection of pyrrhotite activity in both ore and tailings. The relative importance of bacterial and chemical mechanisms in the overall leaching phenomenon has not been assessed but both are certainly involved. It is significant to note that essentially all of the

soluble Fe in both drainages is in the ferrous (Fe^{++}) form which contrasts with experience at other mines, particularly where pyrite is the major iron mineral. In the Sullivan case, this may be a further indicator of pyrrhotite activity in its function as a reductant for the ferric (Fe^{+++}) species.

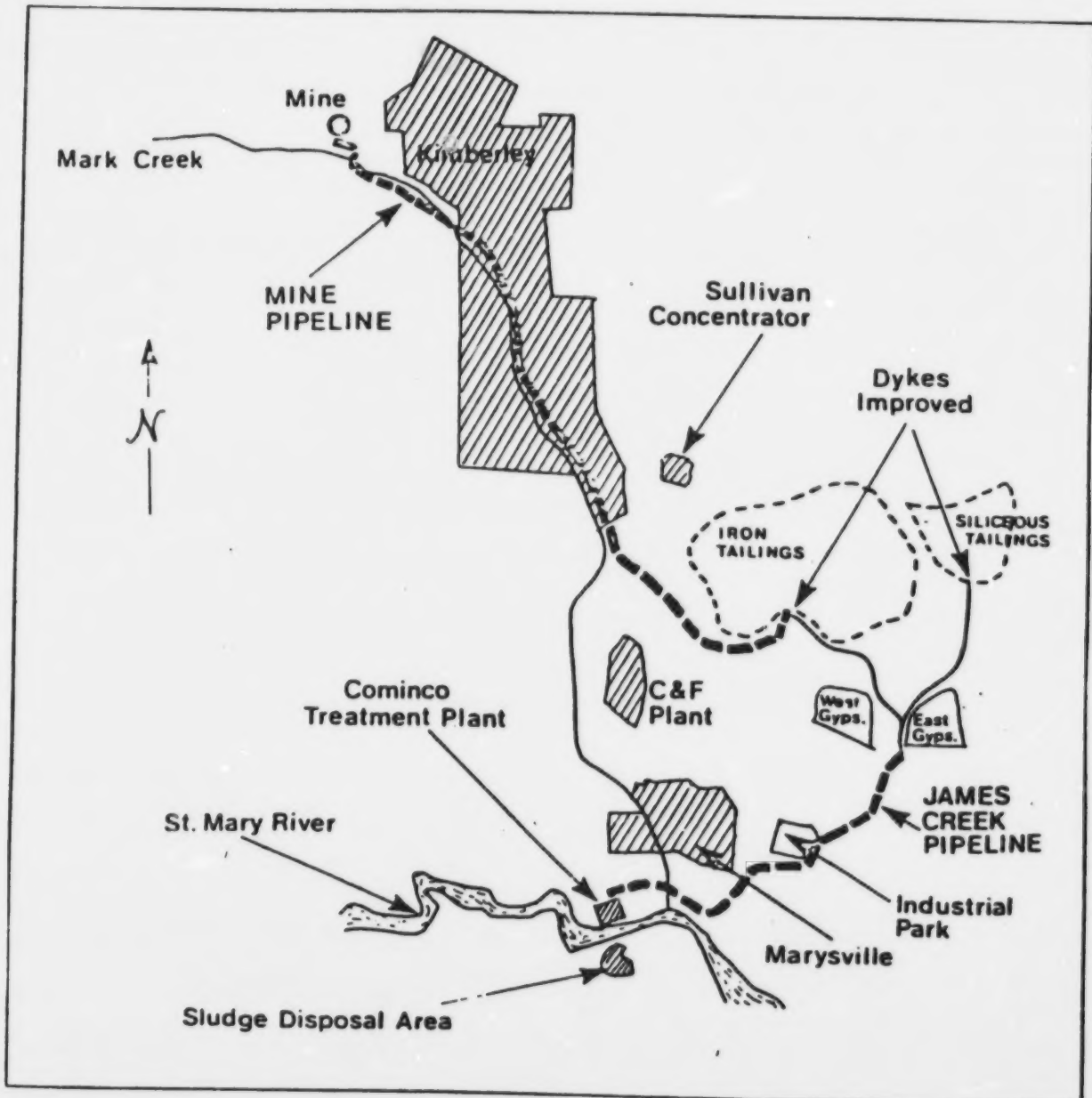
Approximately 90% of the tailings areas are exposed to the atmosphere and this is obviously a major factor in the active leaching in the iron pond. Since 1979, however, the decant pool size in the active area has been increased substantially and the exposed beaches of relatively fresh tailings are generally smaller. It is believed that this has contributed to a generally lower mass loading of soluble metals being produced now than what was experienced prior to the implementation of the present water management system in 1979.

4.2 Abatement of Acid Formation

Cominco has conducted no studies in this direction at the Sullivan. Efforts have been made in the past to achieve the in situ control of soluble metals by the extensive liming of tailings discharge to the ponds. These were unsuccessful as the production of acidity in the ponds always exceeded the alkalinity introduced even at liming rates of up to 25 tpd.

4.3 Treatment Technology

The overall effluent management and treatment system constructed at the Sullivan in 1979 has previously been mentioned and is illustrated in the following figure:

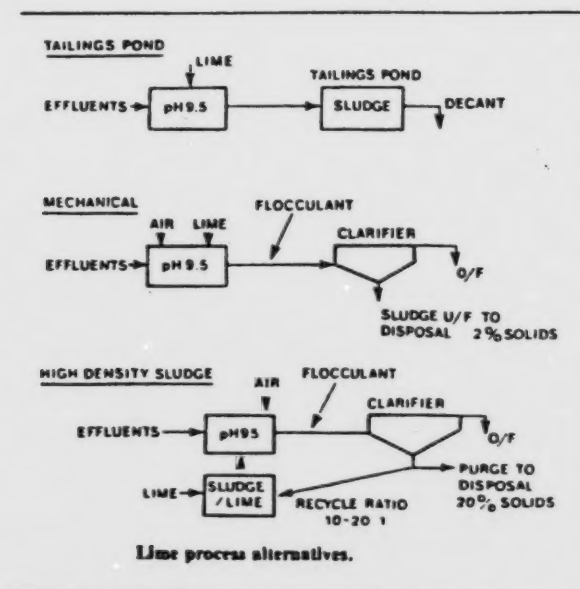


Sullivan Effluents Management and Treatment System

The tailings ponds, particularly the iron impoundment, serve a vital water management function in the mine/mill treatment system but are not used as treatment mediums in themselves. The objectives of the ponds storage system have been outlined in Section II of this report.

The system outlined in the figure was implemented after a careful consideration of the process and logistical aspects which were consistent with a feasible long term tailings management plan. Total capital costs for the project were about \$10 million in 1979 and it has been discussed in the literature by Kuit.

The effluent treatment process alternatives evaluated are schematically outlined in the following figure.



The first employs the tailings pond as the insitu treatment medium and the hydroxide sludge containment. This approach has been successfully used elsewhere, notably at Health Steel Mines², but was judged to be technically inappropriate for application at the Sullivan. As previously mentioned, the direct liming of concentrator tailings could not compete with the production of acidity and soluble metals within the iron pond at reasonable lime addition rates. Therefore, it is clear that this simple process could not viably achieve a satisfactory degree of effluent treatment.

Secondly, it is not consistent with the ultimate range of tailings management as it does not provide for the independent treatment of pond drainages after the operation has ceased. In other words, the prospect continued treatment of contaminated drainage waters must be faced and this issue has been considered in Sullivan planning.

The direct mechanical process in a plant independent of the tailings system was also considered. Widely used and highly efficient with respect to final effluent quality, the process was found to suffer from a difficult to manage sludge management problem due to low solids densities. This factor is particularly severe when high metals concentrations in the feed are involved.

In Cominco's experience with mine drainage treatment at an abandoned mining property, the volume of sludge generated was up to 80% of the drainage volume treated.³

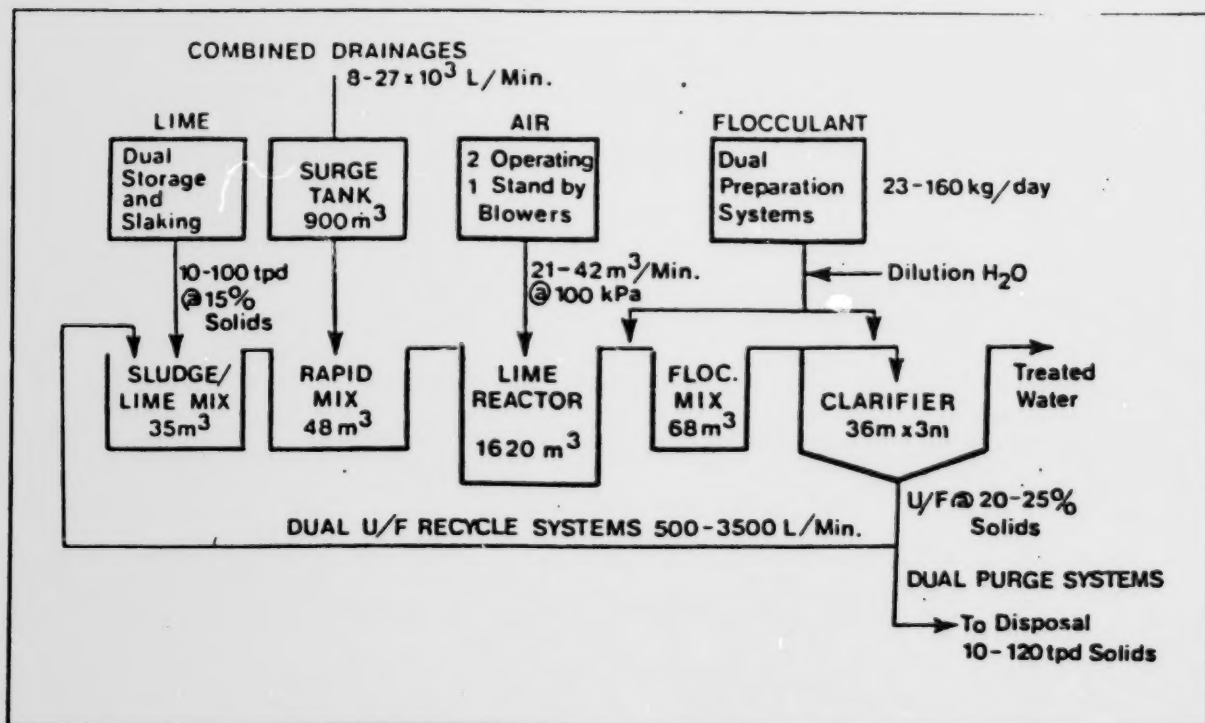
On the other hand, the high density sludge (HDS) version of the basic lime process clearly offered the opportunity for minimizing sludge volumes, was selected and has now been in successful operation at Kimberley for over four years. Employing clarifier sludge underflow recycle and its pre-blending with lime slurry required for neutralization, the plant produces a metal hydroxide sludge for disposal in the pulp density range of 20-30%. This is about ten-fold that which would be generated by the simpler form of treatment. The following data illustrates the importance of this effect in terms of sludge volumes generated when the treatment of the combined drainages is at a rate of 18,000 L/min. and with typical metals loadings:

<u>Sludge Solids Density, wt. %</u>	<u>Sludge Volume, L/day</u>
2	1,310,000
5	505,000
10	245,000
20	119,000
30	75,000

Sludge disposal to the tailings ponds was evaluated but rejected for basically the same reasons that the insitu treatment of drainages was not favoured. The inherent

activity of the ponds would pose a re-leaching problem and the eventual reclamation of the ponds would be hindered by the likely need for sustained sludge disposal. Therefore, a separate and secure area for sludge disposal was selected at Kimberley and this is shown in the plan as being located across the river from the drainage water treatment plant.

The process flowsheet and ranges of major parameters associated with the operation are illustrated in the following figure:



Sullivan Drainage Treatment Plant - Process Flowsheet

Design is based on a normal maximum treatment rate of 18,000 L/min. but operation at a forced rate of 27,000 L/min. during the spring can be managed well using the ponds for freshet storage and flow attenuation. The key reagent supply systems (lime, flocculant, air) were sized on the basis of forecast peak demand which has never been reached. Pumps and supply systems are duplicated and interlocked to allow for automated operation although the plant is normally manned by one operator.

Lime slurry and recycled clarifier underflow sludge are blended in the sludge/lime mix tank at the head of the process, a stage vital to maintaining satisfactory sludge properties. Partial neutralization of the raw drainages is subsequently achieved in the rapid mix tank and completed with iron oxidation at a pH of about 9.0 in the large lime reactor. Complete oxidation of all ferrous iron in the feed is essential to optimize process chemistry and physical performance.

Iron oxidation achieves co-precipitation and adsorption phenomena associated with $\text{Fe}(\text{OH})_3$ formation that results in lower soluble heavy metal concentrations than those derived from hydroxide formation alone. With full oxidation, solids exhibit superior settling properties and form a sludge which is much less viscous than non-oxidized solids. Finally, incomplete ferrous iron

oxidation during treatment can result in chemical instability of impounded sludge and the re-dissolution of heavy metals. This is made manifest by a subsequent oxidation of ferrous hydroxide on exposure to the atmosphere and the generation of acidity.

The typical major operating parameters of the plant are as follows:

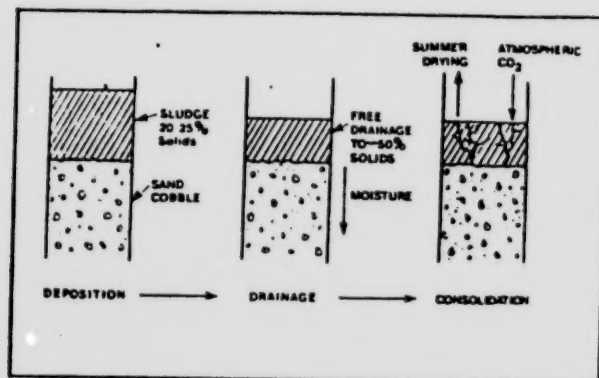
treatment rate:	18,000 L/min.
lime (CaO) consumption:	15 tonnes/day
flocculant consumption:	50 Kg/day
sludge solids production:	18 tonnes/day
sludge volume production:	(250 g/L) 72,000 L/day
recycle rate:	900 L/min.

The sludge purge to impoundment is intermittent and can be as infrequent as once per week depending on the solids inventory in the treatment plant system. About 200 tons is the maximum which can be accumulated without detrimental impacts on clarity and clarifier mechanism torque being incurred.

The sludge impoundment facility in use across the St. Mary River has a total capacity of about 200 years sludge production at the current rate. The actual impoundment technique is not one of slurry ponding and there is no decant from the facility. Sand and cobble comprise the underlying ground which has excellent drainage

characteristics, an important feature in insuring the long-term environmental safety of the impounded sludge solids.

The changes which occur in the sludge following discharge to impoundment are illustrated in the following figure:



Changes in Impounded Sludge

Initially, the material naturally dewateres to about 50% solids and summer drying removes additional moisture. This causes shrinking and with the ingress of air, atmospheric carbon dioxide reacts with excess lime in the solids forming a calcium carbonate matrix which provides a good measure of physical stability. The routine monitoring of wells around the impoundment has indicated no change in groundwater properties other than a slight increase in alkalinity which was expected. Extensive laboratory testing on sludge solids has confirmed the material to be chemically stable under the range of

natural conditions prevalent in the area.

The overall effluents management and treatment system in place at the Sullivan was planned for effective performance and from the perspective that it may well have to operate after production at the property has ceased. Annual operating costs for the system approach \$1 million/year and this is presently a significant economic burden on the operation. Naturally, this would be amplified if the current level of treatment were necessary during the abandonment phase. Planning for future requirements is now based on surface revegetation of the active tailings as being the vehicle to, at least, substantially reduce the contaminant loads generated in the ponds. There is, however, no technology by which to address this problem in the mine other than by measures to reduce infiltration rates from the surface.

WJKuit/jb

January 12, 1984

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2. Busse, E., Acid Drainage Control and Water Treatment at Heath Steele, CIM Bulletin, November 1974.
3. Kuit, W.J., Jackson, H.E. and Mattson, R.M., Treatment of Acid Water at the Wedge Mine, New Brunswick, CIM Bulletin, October 1977.



ENVIRONMENTAL CONTROL

Mine and tailings effluent treatment at the Kimberley, B.C. operations of Cominco Ltd.

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ABSTRACT

Complex facilities which provide for the collection, management and treatment of effluents emanating from the Sullivan mine and concentrator tailings were made operational in October 1979. Key features of the system are the use of upgraded tailings ponds for the storage of up to 800 million litres of metals-contaminated effluents, a treatment plant employing lime in a high-density sludge process and a sludge-impoundment facility designed for maximum long-term environmental safety. The completed works are capable of satisfying a difficult range of operating requirements imposed by highly variable weather conditions, drainage flows and soluble metals loadings. Final capital expenditures for the project approached \$10 million and annual operating costs are about \$0.8 million.

This paper discusses the Kimberley effluents treatment project and the major considerations in its development. The treatment process, major plant equipment and initial operating experience are also described.

Introduction

Cominco Ltd. has worked the Sullivan orebody at Kimberley, B.C. since 1909 and has operated a concentrator some 5 km distant from the mine since 1923. Over the last 70 years, in excess of 120 million tonnes of ore have been mined, and production continues at an average rate of 6,500 tonnes per day. It is

a well-known fact that the contribution of this operation to Canada's mining industry and, in particular, Cominco's development has been significant. However, this success has not been without some undesirable side effects.

Unfortunately, the Sullivan is one of only a few major Western Canadian orebodies which may be classed as "acidic" in nature. That is, the primary economic minerals, galena and marmatite, are enclosed in a siliceous host rock with abundant pyrrhotite, but with little or no accompanying alkaline gangue minerals such as calcite and dolomite. The unavoidable consequence of mining such an ore is that contact with air and water generates an acid mine drainage containing various soluble metals originally present as minerals.

This problem also arises in the concentrator's tailings ponds, which, in the case of the Sullivan, are two separate impoundments of different materials. The 1,100 tonnes/day of "iron" tailings are primarily pyrrhotite which is surplus to the requirements of a separate operation that produces sulphuric acid as an intermediate to phosphate fertilizers. Inert gangue minerals with only a minor sulphide content are the main constituents of the 1,200 tonnes/day of siliceous tailings. Corresponding to the relative proportion of sulphides in the solids, the decant from the iron tailings is substantially more contaminated than that from the siliceous pond.

Until 1979, both the mine and tailings effluents eventually reported to the St. Mary River, south of Kimberley, without treatment. A noteworthy feature of these effluents, however, is that the principal contaminant is soluble iron with smaller proportions of the more toxic heavy metals, such as lead and zinc. Biological monitoring in the river downstream from the effluents' points of entry has continued to show an abundance of aquatic life forms, and the concentrations of heavy metals have been far below acutely toxic values even without treatment. The impact most evident has been discoloration of stream beds by iron staining.

Cominco was originally issued an effluent discharge permit in 1967 under terms of the B.C. Pollution Control Act, which was promulgated in the same year. A subsequent amendment required the company to undertake treatment of the mine and concentrator effluents to specified values by the end of 1977. Studies were started in 1974 with the intent of meeting this objective, but it was not achieved due to a number of delays, some of which were beyond Cominco's control. An application to extend the compliance date to December 31, 1979 was eventually successful and the facilities constructed to satisfy permit requirements were officially commissioned on October 19, 1979.

Mine and Concentrator Effluents

As is common in most mining operations, the Sullivan mine drainage is a combination of surface water that has infiltrated



W.J. Kuit

Walter J. Kuit was born and educated in British Columbia and, since graduation in chemistry in 1966, has been employed by Cominco Ltd. He has conducted a range of chemical and metallurgical research assignments which, since 1972, have been mainly related to process development for effluent control from mining and metallurgical operations. His experience has also ranged from external consulting activities to field supervision of effluent treatment operations. He is currently senior research chemist at Cominco's Technical Research Centre in Trail, with main responsibilities for effluent treatment and chemical process research.

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Keywords: Environmental control, Effluent treatment, Tailings, Cominco Ltd., Water treatment plants, Lime, Flocculents, Clarifiers, Impoundment.

through the fractured orebody and that pumped in for drilling. The drainage leaves the mine through the 3900 level portal, and about 70% of the total flow is intercepted and discharged by gravity. Water penetrating the lower levels is collected in sumps and pumped a total lift of 480 m to the 3900-level ditch. The cyclic nature of the lower-level drainage pumping normally causes substantial instantaneous variation in the mine discharge rate. Retention in the mine's natural hydraulic system is such that the full impact of high surface infiltration rates requires at least one week to be reflected in drainage volumes. The average annual discharge rate is about 3,000 L/min. in a range of 1,200-10,000 L/min. Typical soluble metals concentrations and other properties of the mine drainage are given in Table 1.

Periods of high flow and high metals concentrations often are simultaneous, such as in the spring freshet due to a "flushing" of sulphate salts accumulated in rock fractures. Virtually all of the dominant parameter, soluble Fe, is present in the ferrous (Fe^{++}) oxidation state.

Prior to this project, the drainage was acutely visible to the community of Kimberley, as it directly discharged to Mark Creek, which flows through the town before entering the St.

Mary River. Because both the city and Cominco draw water from an upstream location on the creek, the mine drainage has been a substantial proportion of the total flow during dry periods.

The impact of precipitation and run-off is even more severe on the decant volumes from the concentrator's iron and siliceous tailings ponds, which cover area of 240 and 112 hectares (590 and 280 acres) respectively. Rapid snow melt during warm spring days and heavy rains cause extremely high rates of water influx that can change, virtually on an hourly basis. Dyke protection has, until the present, dictated that the decant pool sizes be minimized and, consequently, little or no attenuation of these flows was possible.

The quality of the effluents from these two sources is quite different. Because the siliceous tailings are largely inert gangue minerals, decant from this pond usually contains only minor contamination, but soluble Mn and Fe concentrations can reach 15 mg/L and 75 mg/L, respectively, on rare occasions. As a rule, the pH is near 7.0 and most bio-assays fail to demonstrate acute toxicity. Instantaneous maximum decant flows can approach 23,000 L/min., but the annual average is about 4,000 L/min.

Decant from the iron tailings is, as would be expected, significantly more contaminated, because the 240 hectares surface area of essentially pyrrhotite is for the most part exposed to the atmosphere. Oxidation generates the same soluble metals as are present in the mine drainage, but in different proportions, and Fe is even more dominant, as Table 2 indicates.

An important feature (with respect to treatment) corresponding with the mine drainage is that all of the Fe is present in the ferrous (Fe^{++}) form. Peak instantaneous flows of 55,000 L/min. have been recorded, but 6,000 L/min. is a typical annual average.

Both tailings decants have been transported by 0.64-m (24-in.) clay-tile piping to adjacent Parshall flumes south of the ponds. There combined, the flows formed James Creek, which discharged into the St. Mary River.

TABLE 1. Mine drainage properties

Parameter	Range
Fe, mg/L	200 - 1,000
Zn, mg/L	30 - 200
Mn, mg/L	20 - 75
Al, mg/L	35 - 150
Pb, mg/L	2 - 5
Suspended Solids, mg/L	200 - 900
pH	2.8 - 4.0
Temperature, °C	8 - 12

TABLE 2. Iron tailings decant properties

Parameter	Range
Fe, mg/L	300 - 2,500
Zn, mg/L	10 - 50
Mn, mg/L	5 - 30
Pb, mg/L	2 - 8
Suspended Solids, mg/L	25 - 100
pH	3 - 4.5
Temperature, °C	0 - 15

Effluents Treatment Alternatives

Studies originally commenced in 1974 were primarily directed toward developing the most viable process option for the treatment of mine drainage alone, because this was, at the time, considered to be the most urgent effluent problem. This was soon followed in 1975 by a change in scope to incorporate tailings effluent treatment, and several engineering studies ensued. The complexity of the project increased substantially as it became evident that options were available in the following key areas:

- (1) treatment process;
- (2) location of treatment facilities; and
- (3) plant flow design—single or split stream.

Treatment Process

Preliminary investigations were conducted at Cominco's Technical Research Centre on a variety of treatment methods, but it became clear that viability could only be achieved using lime as a neutralizing reagent and metal precipitant. The relevant chemistry has been well documented and a review here is not required, but the practical process options merit discussion.

The first scheme, outlined in Figure 1, essentially involves the addition of lime to the contaminated effluents and mixture with a concentrator's tailings discharge. Sludge solids clarification and storage is then an integral part of tailings impoundment. Very low in cost and applied successfully at other operations, such as Heath Steele Mines⁽¹⁾, it was evaluated as being technically unsuitable for use at Kimberley.

The direct "mechanical" process requires an independent plant incorporating a major vessel for lime reaction and aeration (to oxidize Fe^{++} to the more stable Fe^{+++} state), followed by a clarifier or settling pond. Although widely used and highly efficient with respect to achieving good final effluent

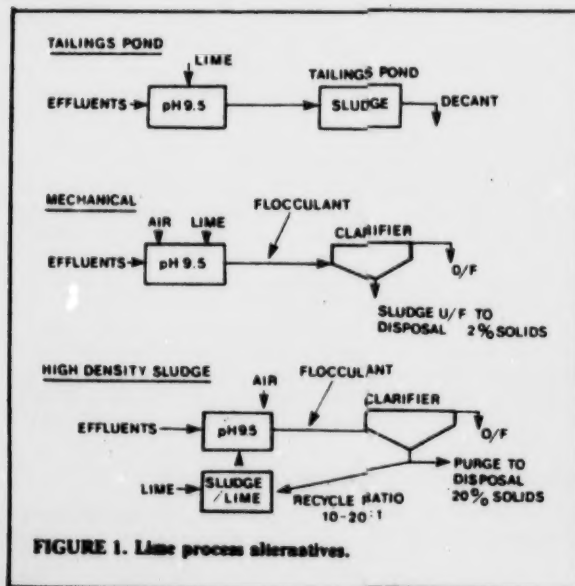


FIGURE 1. Lime process alternatives.

quality, the process can suffer from a difficult-to-manage sludge handling problem due to low solids densities. This factor can be particularly severe where high soluble metals concentrations are involved. One mine drainage treatment operation has been documented in which the volume of sludge generated was up to 80% of the effluent volume treated⁽²⁾.

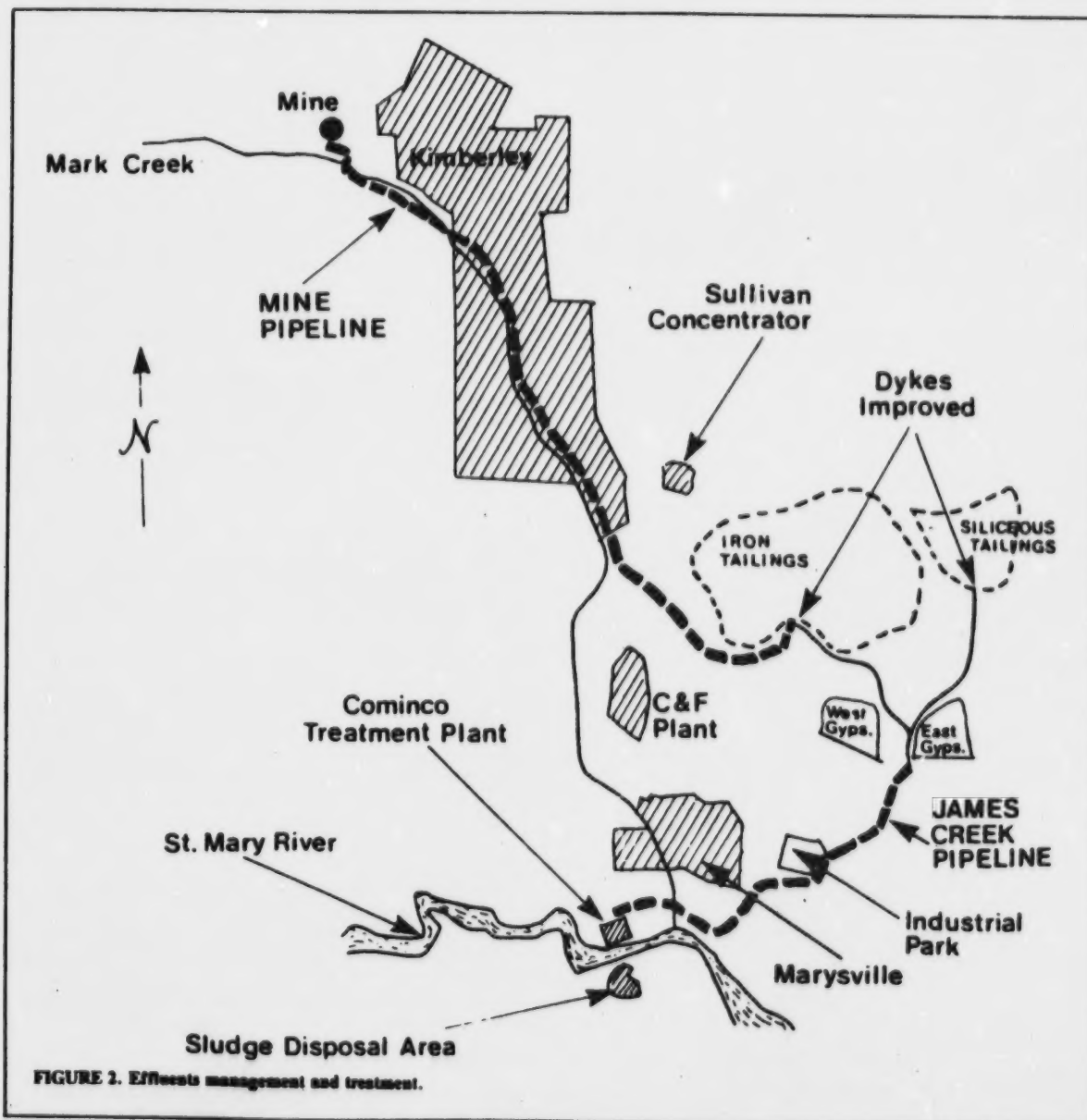
The high-density sludge (HDS) version of the basic lime process offers the attractive potential for minimizing waste sludge volumes and was intensively researched for application at Kimberley. Originally discussed by Kostenbader and Haines⁽³⁾, the HDS process recycles a substantial proportion of clarifier underflow (U/F) sludge, which is blended with lime slurry required for neutralization prior to the main reaction vessel. This pre-mix is a key function in achieving an inherent modification of sludge solids from a fluffy slime to an almost particulate texture. Incentive for the process is illustrated by Table 3, which correlates the daily volume of sludge to be handled by a facility operating at various U/F consistencies. Calculated values are from a Kimberley case of treatment at 18,000 L/min. and 1 g/L sludge solids production. The impact of this data plant operation and sludge disposal requirements

TABLE 3. Sludge volume - solids content relationship

U/F Solids, Weight %	U/F Volume, L/Day
2	1,310,000
5	505,000
10	245,000
20	119,000
30	75,000

is readily evident.

HDS process superiority was confirmed in extensive continuous-flow "mini-plant" studies with a small unit operating at up to 1 L/min. Both the B.C. Pollution Control Branch permit requires and the Federal Guidelines for the mining industry could be satisfied on the full range of Kimberley effluents. Furthermore, the excellent sludge properties arising from recycle were accompanied by near complete control of gypsum scaling as an additional benefit of higher solids loading.



Treatment Plant Locations

The process studies clearly defined lime-HDS as the treatment system of choice, but plant location was a question to be resolved. Included as important criteria influencing site selection were a recognition of the needs for safe sludge impoundment and sufficient system flexibility to handle long-term treatment requirements.

Separate plants to treat mine and tailings effluents were evaluated in engineering studies, which firmly concluded that such a strategy would not be viable. Costs were extremely high and serious technical differences became apparent, particularly with respect to the mine plant. Another proposal consisted of a single facility to handle all effluents located near the tailings ponds with direct piping of the mine drainage to the plant. However, sludge impoundment in either of the tailings ponds was not practicable and ground conditions in the vicinity were found to be unfavourable for the construction of a separate diked storage area.

Soon thereafter, locating the plant immediately adjacent to the St. Mary River, about 8 km south of the mine and 3 km southwest of the tailings ponds, became a viable option. A substantial area of land across the river was found to be suitable for long-term sludge storage requirements. Separate piping of the mine and tailings effluents to the river location was a feature of this proposal.

Flow Design Concept

The river location study was completed through to the engineering feasibility level on the basis of a "twin-gut" treatment plant. That is, the retention requirements of key components such as reaction vessels and clarifier were split between duplicated systems to ensure maximum facility reliability. Without the capacity to store exceptionally large volumes of contaminated effluents ahead of the plant, this design concept would at least provide a "compromise level" of treatment in the event of mechanical breakdowns. The design treatment capacity of the plant was 18,000 L/min. (14,000 L/min. annual average rate), which could be forced to 27,000 L/min. with some sacrifice in effluent quality.

However, the problem of dealing with rates above 27,000 L/min. during the spring freshet remained, and the operation was to be scheduled on the basis of the following order of treatment priorities: mine drainage > iron tailings decant > siliceous tailings decant. Substantial volumes of untreated effluent would have been discharged annually, and the need for correcting this deficiency and simplifying the plant operation was recognized. Therefore, Dames and Moore was retained to study the feasibility of actually using the tailings ponds to store effluents and regulate their discharge. This investigation, which proved the concept to be technically sound and viable, permitted the plant design to be reduced to a "single-gut"

system with improved costs and superior reliability.

Subsequently, the project was mobilized starting in January 1978, and construction was largely completed by the late summer of 1979. Important locations in the Kimberley system are illustrated in Figure 2, and features within the major scope areas will now be described.

Effluent Collection and Management

Mine Drainage

The collection system at the mine provides for the pick-up of the major effluent (3900 level drainage), mine dry septic tank overflow and miscellaneous waste dump drainages. Prior to being piped to the "iron pond", the flow is passed through a "grit chamber" which consists of parallel rectangular settling tanks for the capture of heavy solids which might otherwise settle and accumulate in the line at low flow rates. The pipeline is constructed of 0.36-m (14-in.) diameter polyethylene and extends for 6,900 m to the iron pond, with Air-Vac and blinded drain valves built in at strategic locations. Its design capacity is 11,500 L/min. under gravitational head alone. The line is fitted for "pig" injection and recovery, a procedure which is routinely implemented with a radio tracer-equipped Polypig.

Effluents Management

Creation of a water management capability in the tailings ponds has required a major dyke upgrading program. The lifts placed have been designed for the safe retention of about 2 m of additional hydraulic load. Compacted siliceous tailings were used for construction, with volumes of 124,000 m³ and 36,000 m³ being placed on the existing iron and siliceous dyke structures, respectively.

The objectives of the pond storage system are illustrated in Figure 3 (maximum instantaneous pond influx rate are indicated to emphasize the importance of flow management). About 800 x 10³ L capacity has been provided for the control of peak freshet volumes. It is expected that during spring, the treatment plant will operate at a 27,000 L/min. rate for periods of time which are essentially controlled by weather conditions. Effluents storage will permit plant shutdowns for maintenance and some degree of "blend-optimization" of the different strength decants. Additional benefits are the levelling of strength fluctuations and improved suspended solids control.

The effluents management phase of the project was not fully complete until the late spring of 1980, when remote control valve assemblies in the decant structures were made operational. These allow full flow control from the treatment plant and prevent fluctuations that would otherwise be caused by relatively small head changes.

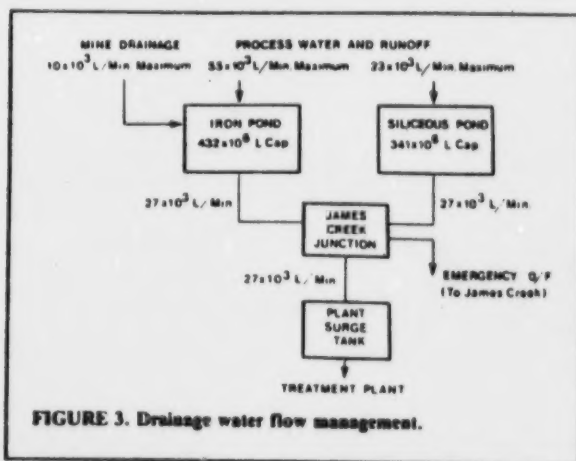
Treatment Plant Feed

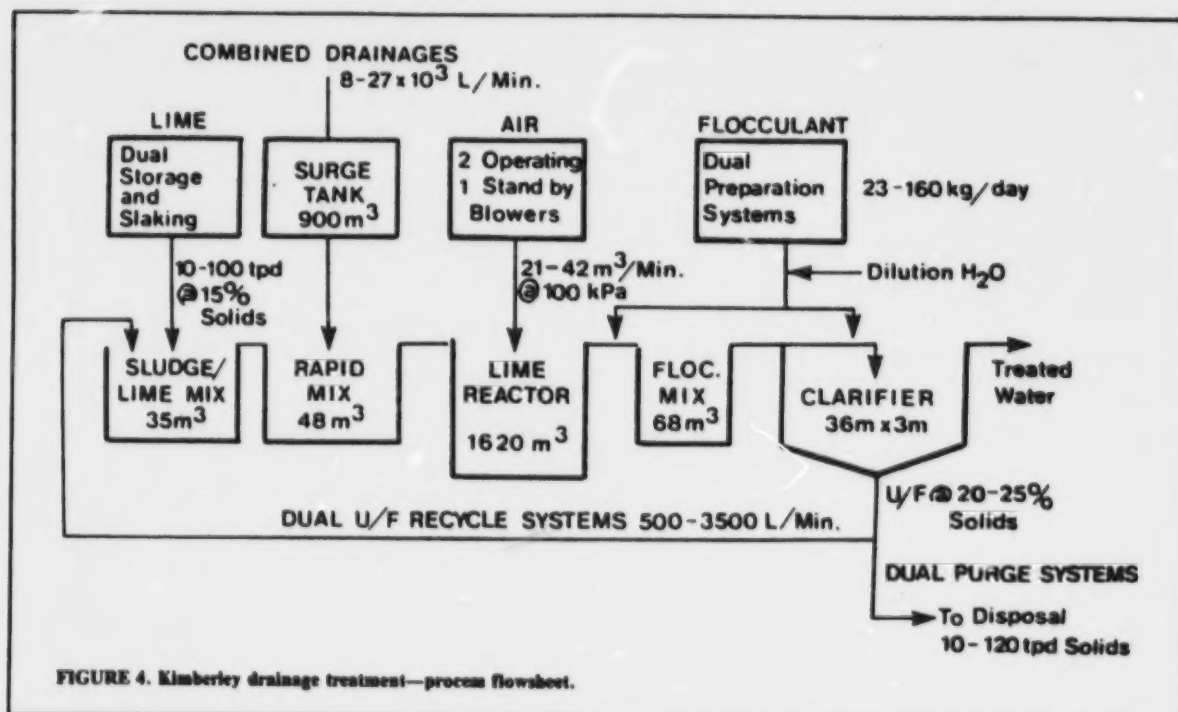
The two pond effluents are directed through the existing decant lines and flow measuring flumes which are recorded in the plant. They are then combined in a junction box which is designed to allow dumping of the less contaminated siliceous decant in emergency situations. The James Creek pipeline varies from 0.46 m (18 in.) to 0.56 m (22 in.) over a total length of 3,600 m. It is designed for a maximum flow of 34,000 L/min. and is fitted with protective devices similar to those on the mine drainage line.

The combined effluents flow discharges to a 900,000-L-capacity surge tank constructed of acid-resistant concrete at the plant site which is operated by level control instrumentation. Storage of the effluent volume contained in the James Creek line will be possible in the event of a forced plant shutdown, or this vessel can be bypassed with the flow going directly to the plant.

Effluents Treatment Plant

Design is based on achieving optimum performance at a normal maximum of 18,000 L/min., but operation at a forced rate





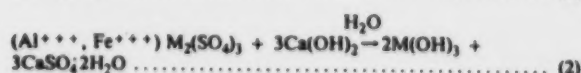
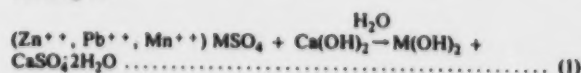
of 27,000 L/min. during the spring can be managed. The key reagent supply systems (lime, air, flocculant) are sized on the basis of forecast peak demand, but shortened retention times may cause some deterioration in final effluent quality. Process design was based on extensive mini-plant testing conducted previously at Cominco's Technical Research Centre in Trail, B.C. All possible operating parameters, including effluent temperatures as low as 0°C, were simulated in the small-scale unit, which obviated the need for pilot-plant confirmation.

Plant Process

The process flowsheet and ranges of major parameters associated with the operation are illustrated in Figure 4. Important features of the system will now be reviewed.

Lime slurry and recycled clarifier U/F sludge are blended in the sludge/lime mix tank at the head of the process. This step is of vital importance with respect to maintaining satisfactory sludge properties. The sludge/lime mixture discharges to the rapid mix tank, which achieves a partial neutralization of the contaminated effluent entering the plant. Smooth final pH control at the optimum value of 9.5 in the subsequent large reaction tank depends on feed-back regulation of the lime slurry based on the pH in the vessel.

The principal treatment tank, the lime reactor, provides a retention time of about 50 min. at the maximum combined flow of raw effluent and sludge recycle. Near complete precipitation of metals as hydroxides occurs directly at this stage according to:



However, optimum process chemistry and physical performance require complete oxidation of ferrous hydroxide to the more stable ferric hydroxide as indicated by:



Virtually all of the plant feed soluble iron is in the Fe⁺⁺

TABLE 4. Typical operating parameters

lime (CaO) consumption:	20 tonnes/day
flocculant consumption:	(3 mg/L) 80 Kg/day
sludge solids production:	26 tonnes/day
sludge volume production:	(250 g/L) 104,000 L/day
recycle rate:	(15/1) 1,100 L/min.
sludge purge frequency:	once (150 tonnes) every 6 days

form, and oxidation by aeration under high shear agitation provides the following:

Optimum Chemistry—Co-precipitation and absorption phenomena associated with Fe(OH)₃ formation result in lower soluble heavy metals concentrations than those derived from hydroxides alone.

Clarifier Performance—"Oxidized iron" solids exhibit superior settling properties and form a sludge that is much less viscous than the non-oxidized solids.

Sludge Stability—Incomplete Fe⁺⁺ oxidation during treatment can result in chemical instability of impounded sludge and re-dissolution of heavy metals.

With the chemical reactions completed, the discharge from the lime reactor is treated with dilute flocculant solution prior to entering the gently agitated floc mix tank. This vessel was incorporated into the process to ensure good floc formation prior to clarification.

The clarifier O/F discharge to the river is monitored for flow rate, turbidity and pH, with daily composite samples taken for metals analyses. Thickened U/F sludge of about 20-30% solids content (250-350 g/L) is then either recycled or purged to the impoundment area. The recycle rates are so controlled that 10-20 Kg of solids are returned to the head of the process for every Kg precipitated from the plant feed. Therefore, 90-95% of the solids loading in the system is recycled material.

The frequency and duration of sludge purging is determined by the rate of production. Under peak metals loading to the plant, the frequency can be once every day for a maximum of 6 hours of pumping. A total solids inventory of about 200 tonnes is probably the operating maximum that can be ac-

accumulated without having a detrimental impact on the plant (i.e. clarity, clarifier mechanism torque).

Operating parameters will vary greatly, but typical conditions can be illustrated from the plant treating 14,000 L/min. containing, as the major soluble metal, 400 mg/L Fe.

Plant Equipment

The general arrangement of the main plant components is illustrated in Figure 5. A fundamental design criterion of the facility was that it eventually should function with a minimum of attention, including periods when an operator would not be present. Therefore, manual labour requirements in the plant are minimal, with key systems being duplicated and interlocked.

Lime System—Twin 140-tonne silos equipped with bin activators provide pulverized quicklime storage. Screw feeders of 15 cm (6 in.) diameter supply BIF slakers, which are each rated at 3,200 Kg/hr. lime, producing a slurry of about 15% consistency. This is stored in an agitated tank below floor level which has 1.5 hour storage capacity at the peak lime demand of about 100 tonnes/day. Interlocked 15-hp Morris vertical pumps, rated at 900 L/min. each, supply the pressure-controlled lime feed loop.

Flocculant System—The two interlocked flocculant solution preparation and feeding packages are automated and utilize the BIF Polypac systems. These disperse dry flocculant particles by the drum-wetting principle to ensure solution preparation with minimal "fish-eye" formation. The feed hoppers of each unit are occasionally charged by a Vac-U-Max loading system from ground-level storage. Metering pumps feed solution at 5 g/L concentration, and this is reduced to 0.25 g/L with fresh water in a Kenics static mixer before application.

Air Supply—Three 75-hp Gardner-Denver "cyclo-blowers" are installed below the elevated rapid mix tank to supply air for iron oxidation in the lime reactor. Each has a capacity of about 21 m³ (750 cf)/min. at 100 KPa (14.7 psi). Normal plant operation will utilize only one blower, with two being on line during peak requirements. The third is intended as a stand-by unit during this period.

Process Tanks—The main process flow through the plant (sludge/lime mix to clarifier) is by insulated launders which are designed for 34,000 L/min.

Sludge/Lime Mix : Mild steel construction, 3.6 m dia. by 3.9 m, 10-hp Denver, spindle bearing agitator.
Rapid Mix : Stainless construction, 4.2 m dia. by 3.9 m, 15-hp Denver, spindle bearing agitator.

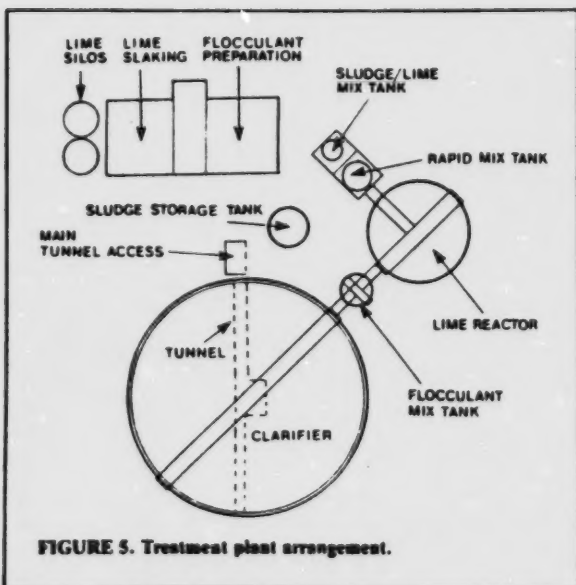


FIGURE 5. Treatment plant arrangement.

Lime Reactor : Concrete construction, 15.2 m dia. by 9.7 m, 150-hp Lightnin, reducer drive, 48 rpm. Flat-blade disk turbine impeller, 2.1 m dia. (crown plate distributor below turbine.)
Flocculant Mix : Concrete construction, 4.8 m dia. by 4.2 m, 3-hp Denver, reducer agitator.

Clarifier—The vessel is concrete and measures 36 m dia. by 3 m. Peripheral O/F is provided by submerged ports, with a weir controlling the level, and the vessel is designed to operate with an ice cover. The mechanism is an Envirotech-Eimco type B heavy-duty unit operating at .08 rpm. One 3-hp drive is installed, which gives a torque rating of 240,000 Nm (175,000 ft lb), but this can be doubled by the installation of a second drive. The rake blades are attached to the arms by 0.7-m "thixo-posts", a design that facilitates raking of the viscous sludge. An automatic rake lifting and lowering system is another feature of the mechanism.

Clarifier U/F Handling—Two independent pumping systems are located in a service tunnel beneath the clarifier.

Sludge recycle is by two Canadian Allis Chalmers SRL pumps driven by interlocked 25-hp Asea D.C. variable-speed motors. The capacity of each is 3,800 L/min. under an 18-m head. Separate 20-cm (8-in.) lines feed a nuclear densitometer-equipped Parshall flume, which discharges directly to the sludge/lime mix tank. The recycle system is also designed to fill and pump from the 6-m-dia. by 6-m emergency sludge storage tank shown in Figure 5. This feature will only be used in the event of a plant shutdown which requires the clarifier to be emptied. A stock of dense sludge is a process necessity to ensure that equilibrium operating performance prevails immediately after the plant is re-started.

Sludge purging to storage about 700 m from the plant is done with parallel 60-hp Morris SRL pumps capable of pumping 4,000 L/min. of the thixotropic material. Additional lime, equivalent to approximately 4% of the sludge solids, is added to the sludge during discharge. The two 15-cm (6-in.) diameter, insulated steel lines have four primary discharge locations in the impoundment area and are graded to drain back to the plant. Clarifier O/F is used to flush the lines following each purge.

Sludge Impoundment

The sludge impoundment facility in current use will provide a minimum of 5 years storage capacity based on an average volume accumulation of 55,000 m³/year. Only modest dyke construction, requiring 19,000 m³ of local borrow material, was necessary to provide this Stage I storage capacity. Further development of the site can provide sludge impoundment for in the order of 90 years of plant operation if required. A practical utilization method for this material is obviously desirable, and this search will continue.

It must be emphasized that the impoundment technique is not one of slurry ponding. There is no decant from the stored sludge, as the underlying ground is a mixture of sand and cobble which provides good drainage characteristics without solids escape. Studies have demonstrated that the rapid drainage of water originally present in the sludge or from subsequent precipitation is essential to the development of properties that will ensure long-term environmental safety.

The desired changes which occur in sludge discharged to the impoundment area are illustrated in Figure 6. Initially, the material naturally de-waters to about 50% solids, with the drainage reporting to the water table and eventually the St. Mary River. The quality of the drainage water is the same as that which the plant directly discharges to the river, and this is being monitored by sampling from wells installed at strategic locations. During the winter, freezing of the sludge is a limiting factor, but this effect results in enhanced drainage characteristics following spring thaw. Summer drying removes additional moisture, causing shrinkage which allows the ingress of air. This initiates the function of the extra lime intentionally added before discharge from the plant. Atmospheric

carbon dioxide (CO₂) reacts with the lime, forming a calcium carbonate (CaCO₃) matrix in the relatively porous solids, thus providing a measure of physical stability and assisting the permanent fixation of heavy metals. Table 5 illustrates a typical chemical analysis of the sludge, showing the significant metals present.

The discharge points in the impoundment area are cycled to give deposited sludge the maximum exposure time possible before being covered by fresh material. Lengthy cycle times are augmented by the plant's capacity to store sludge solids with only intermittent purging. Leach tests on sludge which has undergone this impoundment cycle have yielded virtually no dissolution of heavy metals under the range of natural conditions prevalent in the area.

Operating Experience

As the facilities have been operational for only about one year, a full assessment of long-term performance cannot be made at this time. At least several years will be required to confirm water management and treatment plant capabilities under the complete range of operating demands.

Mine drainage piping to the iron tailings pond was operational in April 1979, and this system has performed satisfactorily, achieving an immediate improvement in the quality of Mark Creek water which has drawn favourable community reaction.

Plant Operation

The initial operating trials commenced in early September and the plant was officially commissioned on October 19, 1979. An operator and a helper initially manned the plant on each shift, seven days per week, but the complement is now one man per shift and further reductions are planned.

The time requirement for bringing the HDS treatment process to an operating equilibrium was not experienced in the Kimberley plant start-up due to a rather unusual method of preparation. This involved obtaining about 110 tonnes of sludge containing 40% solids from The Bunker Hill Co., Kellogg, Idaho, which operates a similar treatment process⁽⁴⁾. "Seeding" the system using this material proved to be highly effective, as the fresh sludge produced was immediately about 20% solids and high consistencies were readily maintained. The plant initially operated for a period of two weeks at an average feed rate of 10,000 L/min., producing 11 tpd solids, before any sludge was purged to storage.

The over-all operating performance of the facility has been highly satisfactory and the break-in problems normally prevalent in a new plant have been minimal. Key mechanical systems, such as those supplying reagents, and the process control instrumentation have generally operated very well. From the outset, there were no process or mechanical difficulties that prevented the plant from being fully operational. Scheduled shutdowns have been necessary for several minor modifications, but effluents were stored in the ponds during these periods.

Some difficulty was initially experienced with the lime reactor agitator in that the power draw was unacceptably high with only one blower running. Two blowers (42 m³/min. air) had to be run continuously to ensure sustained operation of the agitator, but this was corrected by reducing the impeller

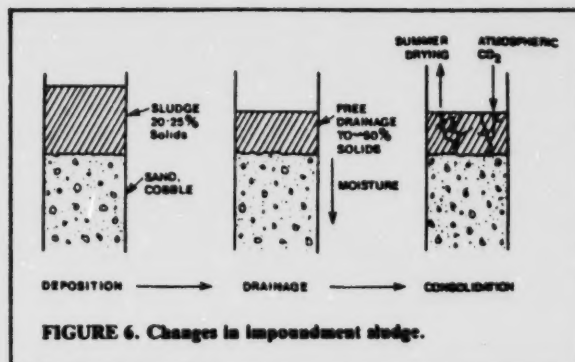


FIGURE 6. Changes in impoundment sludge.

TABLE 5. Metals content of sludge

Metal	Weight %
Fe	19.5
Ca	9.5
Mg	6.0
Si	3.1
Zn	2.1
Al	1.8
Mn	1.2
Pb	0.3

diameter from 2.13 m (84 in.) to 2.06 m (81 in.). Another minor deficiency soon apparent was an inadequate degree of fluid motion in the sludge/lime mix tank caused by the tixotropic properties of the recycled sludge. Air injection to augment the agitator was necessary, but merely removing the tank baffles and increasing the agitator speed corrected the problem.

Development work on the flocculant application system was effective in resolving a slight deficiency with respect to clarity of the plant discharge that developed following start-up. Operation with clarifier O/F suspended solids concentrations of about 25 mg/L was found to be "aesthetically" unsatisfactory, even though it was within the permit requirements. The use of one of several efficient anionic flocculants in a split application method (Fig. 4) now produces suspended solids values of consistently less than 15 mg/L, with the desired visual impact.

Treatment Performance

Results from the first few months of operation have generally been gratifying. The treatment rate has thus far varied from 7,000 to 27,000 L/min., with the feed consisting of both tailings pond decants in a range of proportions. This variation has resulted in diverse feed strengths which are illustrated by the major soluble metal, Fe, being in the range of 30-500 mg/L.

The quality of the treated effluent discharged to the St. Mary River has normally been superior to that yielded by the lab-scale mini-plant studies. It is also remarkable that metals analyses of the final effluent have been very consistent and essentially independent of the loading to the plant. Performance, to this point, has been well within the standards set

TABLE 6. Plant treatment performance

Parameter, Total Values	Plant Feed	Federal Guidelines	Plant Effluent (mg/l)
Fe mg/L	250	—	<1.0
Zn mg/L	22	0.5	<0.2
Pb mg/L	5	0.2	<0.1
Cu mg/L	0.15	0.3	<0.05
As mg/L	.02	0.5	<0.01
Suspended Solids mg/L	75	25	<15
pH	4.5	min. 6.0	9.5

down by both Environment Canada and the B.C. Pollution Control Board. To illustrate this with an example that is meaningful to the industry across Canada, Table 6 compares the typical metals concentrations present in the plant feed and effluent with the monthly average objective values in the Federal Guidelines.

With respect to the plant's other product, impounded sludge, substantial time will naturally be required to prove long-term environmental acceptability. However, initial observations indicate that the desired drainage and consolidation are occurring satisfactorily and there is confidence that expectations will be met.

Conclusion

The completion of this project is the culmination of extensive efforts over several years by various groups within Cominco Ltd. and a capital expenditure of nearly 10 million dollars. Adding to this commitment, of course, is the anticipated annual operating cost of the facility, which will be in the order of 0.8 million dollars. It can be appreciated that these cost burdens are a particularly harsh reality when there is no opportunity for monetary return. Moreover, the operation of the treatment plant will have to be maintained long after the closure of the

mine and concentrator at Kimberley, because the oxidation and leaching of residual sulphides will continue.

However, the facilities were constructed with the objective of providing a comprehensive solution to a difficult effluents management and treatment problem, with emphasis on the criteria of reliability and process effluent quality. Value can only be derived, therefore, from the degree to which results fulfill planning. Although the operating record of the Kimberley system is only brief to this time, performance is confirming the project to be a substantial contribution to the improvement of environmental quality.

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18



CANMET TAILINGS MANAGEMENT STUDY

A Joint Project of Monenco Limited
Noranda Mines Limited, Cominco Limited and
Inco Limited

Tailing Disposal Water Management
Ontario Division, Inco Limited

H.R. Butler,

Safety and Environmental Control

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WATER MANAGEMENT TAILINGS DISPOSAL
ONTARIO DIVISION, INCO LIMITED

INTRODUCTION

There are two areas in Ontario where Inco Limited conducts integrated Mining and milling operations. The two areas, Copper Cliff and Shebandowan, in many respects are similar sulphic deposits of pentlandite, chalcopyrite and pyrrhotite. However, the Shebandowan deposit contains measurable quantities of calcium, magnesium silicate which tends to mitigate against the acid generation potential of the tailings.

Following the erection and commissioning of the Copper Cliff Mill in 1930, water usage was on a once through basis. However, the period of expansion during the 1940s water reuse was required to augment this scarce resource. This reuse of water was reported to have affected unfavourably the mill metallurgy hence a reduction in recycled water.

With the advent of "on line" analytical facilities, the Frood-Stoble Mill came on line in 1967 with a 90% plus use of recycled and untreated tailing decant and mine water effluent. In 1972, when the Clarabelle Mill came on stream, new water consumption had been all but eliminated. New water or freshwater was of potable quality and was limited to use in the laboratory, showers, lunchroom and drinking fountains.

PREOPERATIONAL STUDIES

A short time after the formation of the Ontario Water Resources Commission, it became apparent that any future tailing disposal facility should be preceded by a preoperational study.

The initial study was conducted at the Shebandowan facility. Shebandowan Lake was and is a recreational lake on which are sited numerous summer cottages. It was essential that Inco establish the baseline conditions in order that a proper evaluation could be made of alternative tailings disposal sites and receiving watercourses and ultimately select the optimum candidate.

The preoperational study included a variety of both dynamic and static conditions upstream and downstream. The study included determination of density and diversity indices for benthic organisms, phytoplankton, fish, crustaceans, as well as more traditional chemical and physical determinations such as dissolved heavy metals, pH, turbidity, colour, hardness, etc. Following the commencement of operations monitoring combined in order to evaluate for signs of change in the receiving environment. Degradation was found but considerably less than expected.

An expanded tailing disposal facility is being undertaken at Copper Cliff. There too, baseline conditions have been evaluated for a number of potential alternate sites.

We believe these preoperational studies are an integral part of competent design.

THE TAILINGS DISPOSAL AREA AS A TREATMENT SYSTEM

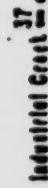
At both Copper Cliff and Shebandowan, the tailing disposal area is an integral part of the mine/mill effluent treatment system.

COPPER CLIFF

The complexity and extent to which the Copper Cliff tailing disposal area is employed as an effluent treatment system is illustrated in Figure 1. The tailing area is the recipient of a wide variety of effluents and materials.

Effluents	- Clarabelle Mill
	- Frood Stobie Mill
	- Copper Cliff Mill
	- Frood Mine
	- Stobie Mine
	- North Mine
	- South Mine
	- Creighton Mine
	- Acid Plants
	- Copper Cliff Smelter

Figure 1



- Sludges
 - Copper Cliff Sewage treatment plant
 - Sudbury Region Sewage treatment plants
 - Copper Cliff effluent treatment plant
 - Electrowinning
- Miscellaneous
 - urban run off - town of Copper Cliff
 - seepage water from tailing berms
 - landfill site effluent

The use of the tailing area as an integral component of the mine/mill effluent treatment system began in 1967 and evolved to its present state. During this evolutionary period, water was first recycled to the Frood-Stobie mill in 1967, then to the Clarabelle Mill in 1972 and in 1973 an effluent treatment plant was constructed to treat up to 275 million litres per day. The effluent quality limits were 0.5 mg/L nickel, 0.5 mg/L iron, 0.2 mg/L copper and 15 mg/L suspended solids. The effluent pH was maintained at about 9.5.

SHEBANDOWAN

The use of the tailing disposal area at Shebandowan originally was not to be used as an integrated mine/mill effluent treatment system. Following extensive consultation with the public and the OWRC, the management of water would be as follows:

- (a) the mine water would be clarified underground and discharged to the environment without further treatment.
- (b) the mill tailings would be pumped to an impoundment basin the water recycled to the mill for reuse both in the mill and for hydraulic backfill. It was expected that the basin would not overflow, even during periods of heavy snow melt, during the life of the operation.

However, shortly after the operations began, it was evident that mine water clarification underground was less than acceptable while the tailing disposal area water was much better than expected. It was agreed that the mine and mill waters would be both discarded into the tailing disposal area and that the effluent flow from the tailing area would be regulated in order to not adversely affect water quality during periods of low flow downstream.

Effluent from the tailing area is currently untreated and the high quality is indicated by the average analysis over the past five years:

pH	7.4	mg/L
Copper	0.003	mg/L
Nickel	0.078	mg/L
Iron	0.109	mg/L
Zinc	0.003	mg/L
Suspended Solids	2	mg/L

The impoundment basin was constructed in order to utilize a swamp around which impervious dams were constructed. Extensive monitoring has confirmed a tight system with no seepage, hence no seepage control facilities are required.

SEEPAGE GENERATION AND CONTROL

Copper Cliff

The construction of berms or dams to impound tailings at Copper Cliff have historically been built employing a starter dam of local borrow and the spigotting tailings on the inside. The control of seepage did not receive a high priority unless the dam stability could be affected.

During the past ten years, seepage impoundment basins have been built to collect seepage. The collected seepage is returned to the active tailing area via level controlled pumps situated within the seepage basin.

Future dams are to be designed in accordance with parameters which considers dam seepage and stability. The seepage will be pumped to the active area.

All drainage from the tailing impoundment area is collected, recycled and/or treated before discharge to the natural environment.

Shebandowan

As previously stated, there is no seepage detected from the dams.

ENVIRONMENTAL CONCERNS

Tailing areas have been and will continue to cover a relatively large expanse in a northern climate where milling operations take place.

1. The use of the motorized sled - snow machine - is a concern when an active tailing area becomes an unauthorized recreational area. Try as you may, you can't keep them out.
2. The blowing tailings during the spring and autumn when high winds are associated with freezing conditions exist but when snow cover is absent. Wind born tailings are a growing problem in areas where the height of the deposit is greater than the local trees. Wherever possible, it is desirable to have trees within the disposal area to act as wind breaks.

During freeze-dry conditions, it is not possible to apply chemical stabilizers to stop the wind pick up of solids because (a) the size of the area involved, (b) the binder viscosity, (c) lack of penetration of the binder into the frozen tailings.

3. Seepage water is generally high in heavy metals and low in pH. These two qualities render seepage not only toxic to aquatic life but also unsightly. The blown stain caused by the iron content and the periodic evolution of hydrogen sulphide are aesthetically undesirable to the public.
4. The control of decant water from the tailing area is vital to the stability of the dams. This is extremely vital when an area becomes inactive. The blockage of the decant structure by natural debris or by beaver cuttings must not be permitted. It would be appropriate for a tailing area prior to abandonment to be finished so that the collection of perched water would be prevented.

5. Tailings disposal areas are often situated in swamps or lakes. Because of this ground water contamination is usually not a problem. However, should the swamp or lake be the source of or connected to an aquifer than contamination from the tailings would be a problem.

RESEARCH - TAILINGS STABILIZATION

1. Genetic Engineering

- plants to fix nutrients from the air
- plants resistant to heavy metal uptake
- bacteria to increase thatch decomposition rate
- chelants to mitigate against heavy metal toxicity
- plants, grasses and trees with faster growth rates and ability to withstand cold (above 50th parallel)
- bacteria which would feed on the thiobacillus bacterium to prevent the formation of thiosalts.

2. Does the hard pan which forms 15 - 20 cm below the tailing surface:

- (a) prevent root penetration by plants and trees
- (b) prevent downward percolation of precipitation and snow melt
- (c) reduce the acid generation of the total tailing mass.

3. A fertilizer which contains phosphate in a form which would remain available to plants and not be tied up by the various metal components in the tailings.

4. Does vegetative cover reduce the

- (a) downward percolation of precipitation and snow melt
- (b) downward penetration of oxygen into the tailing mass
- (c) runoff coefficient.

5. What is the maximum sulphur content of tailings on which vegetation can be expected to grow?
6. The definition of a "walk away" condition.
7. Are organic sludges - sewage sludge - desirable additions to the general tailing mass?

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ATTACHMENT NO. 3
NORANDA SUBMISSION FOR CANMET TAILINGS REPORT
K.G. WHEELAND, 24 JANUARY 1984

TREATMENT OF ACID-MINE WATERS WITHIN
THE NORANDA GROUP

M. Wasserlauf
January 1984

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1.0 INTRODUCTION

In the last decade, Noranda Group companies along with Federal and Provincial bodies have carried out work aimed at defining treatment of acidic mine waters originating from tailings seepage, underground mine sources and surface drainage. This has resulted in the development of lime neutralization treatment technology for acidic waters and the subsequent construction of lime neutralization treatment plants. This report will describe current Noranda Group treatment plants, process and water quality data, and discuss sludge treatment and disposal.

2.0 DESCRIPTION OF TREATMENT PLANTS

2.1 Brunswick Mining and Smelting, Mining Division (BMS-M)

BMS-M operates the No. 12 underground mine and concentrator complex near Bathurst, N.B. with a daily production of 10,000 metric tonnes of ore containing zinc, lead and copper. Open pit mining at its No. 6 mine, situated 10 km from the concentrator, has ceased. The mine operates three water treatment facilities, as follows:

2.1.1 No. 12 Acid Mine Water Treatment Plant

The water treatment plant is located in a 3750 ft² building between the concentrator and tailings pond. Acid water from the mine (335 l gal/min or 91 m³/h) is pumped from an underground sump to a 50,000 l gal (247 m³) head tank, then to the water treatment building. There, the water passes through two 8,000 l gal (36.4 m³) cylindrical steel reactor tanks where it is neutralized by a hydrated lime slurry. Ferrous iron is oxidized to the ferric form by the addition of 150 cfm of 18 psi air to each reactor underneath the reactor mixer impellers. The neutralized water (pH 9) passes by gravity to a flash mixing cell (2 sec retention time), where a high molecular weight anionic polymer is added. The water then flows to the Lamella gravity settler* made up of two plate packs with an

* not currently in use

effective settling area of 2520 ft². The clear overflow is discharged to a diversion ditch, while sludge is taken out of the bottom of the clarifier using Moyno pumps and discharged with the mill tailings to the tailings pond.

Reagent preparation and handling consists of lime and polymer systems. Lime is piped from the mill as a 18-20% slurry to a storage tank in the treatment plant building, and to prevent settling is circulated continuously. Lime addition is controlled by the pH in the second reactor, which prompts automatic valves to discharge the slurry into the first reactor. The polymer system is a packaged BIF unit using dry polymers (Dearborn Aquafloc 462).

Plant instrumentation consists mainly of flow meters and flow control valves for influent and lime slurry, level transmitters for level control in the wastewater headtank and lime slurry tank, and a pH electrode and transmitter. Sludge discharge from the clarifier is controlled by a sludge bed detector.

2.1.2 No. 12 Lime Station

The No. 12 lime station is located 5 km from the concentrator and treats tailings decant water, all contaminated drainage, and any underground water which by-passed the acid treatment plant. Flows vary widely with precipitation and tailings pond operation, falling in the range of 83 to 8300 I gal/min (23.6 to 2360 m³/h). The wastewater is collected in an oxidation holding pond, with part of the water (83 to 165 I gal/min) taken from the pond through a 6 in. stainless steel line. This water passes through an 18 in. steel duct, where dry hydrated lime is added. The resulting lime slurry is piped to a reactor for mixing before overflowing into the main discharge - a 4 ft dia. concrete pipe. The majority of the water from the holding pond flows through a concrete decant tower, through two 16 in. concrete feed pipes, and into the 4 ft dia. concrete pipe, where mixing of the lime slurry and water takes place. The neutralized water is discharged to a ponding system, where solid-liquid separation takes place. The sludge settles out in the ponds, while the decant passes through

polishing ponds before being discharged to South Little River.

The lime addition system consists of a 40 tonne lime silo, with a screw type lime feeder. A 600 ft² building is provided to house a pH monitoring system, as well as electrical equipment. For pH control, a shallow well pump takes a sample from the outlet of the 4 ft D concrete pipe to a pot in the station building. There, the pH is monitored and is used to signal for the control of the lime feeder.

2.1.3 No. 6 Water Treatment Plant

The No. 6 area is the site of Brunswick Mining's open pit mine, which is no longer in operation. Contaminated water from the site and mine water from the open pit are collected in a 17 acre holding pond. The water, averaging 830 to 1250 I gal/min (235 to 355 m³/h) is pumped to a 1050 ft² treatment building. There, it passes in series through two 5800 I gal steel cylindrical mixed reactors with lime slurry added to the first reactor.

Neutralized water from the reactors is discharged to settling ponds. The sludge settles in the ponds, with most of the overflow discharged to Knight Brook, while approximately 250 I gal/min is recycled for the preparation of lime slurry.

The lime system consists of a 40 ton storage silo, a dry lime screw feeder, and a 3100 I gal agitated lime slurry tank. The pH at the outlet of the second reactor is used to control the dry lime feeder. The lime slurry overflows from the slurry tank and pours into the first reaction tank.

Instrumentation consists of the pH monitoring/control system and flow monitoring/control.

2.2 Les Mines Gallen

Les Mines Gallen operates a 1500 ton per day zinc, gold and silver open pit mine approximately 10 km north of Noranda, Québec. Acid drainage from the mine is collected in an underground sump, then pumped (400 I gal/min) to the water treatment plant. There, the water first flows to two 9000 I gal aerated lime reactors in series, where the pH is increased from 3.5 to 9.5. Subsequently, the water passes through a flash mixer, where polymer flocculants are added and on to the Lamella plate pack gravity clarifier with an effective surface area of 2520 ft². Part of the settler underflow is recycled to a sludge reactor. There, lime slurry is added, and the mix is piped to the first reactor. The remaining sludge is discharged to a sludge holding pond. The recycle of sludge results in sludge density in the order of 20%. Overflow from the clarifier passes to a polishing pond, then through a diversion ditch to the Kinojévis River system.

Reagent addition consists of lime and polymer facilities. Hydrated lime is stored in 100 ton bin and is fed via a vibrating screw feeder to a cone, with water added to make up a lime slurry. Lime addition is paced by the pH signal from the second lime reactor. A dry polymer is prepared in a polymer mix system as a 0.1% solution, then fed to the flash mixer proportionally to water flow.

At the control room, the mine water inflow, the pH in the second reactor and final effluent and the turbidity of the discharge are monitored. If critical set points are reached, the plant is shut down automatically.

2.3 Mattabi Mines Limited

The Mattabi mine and concentrator complex is located near Ignace, Ontario. The mine extracts 1000 tons per day of ore containing zinc, copper and lead. Wastewater discharge consists of mill tailings (1900 I gpm) and mine drainage (200 to 700 I gpm) collected in a tailings pond.

The decant water flow to a reclaim pond with sixty percent of the reclaim water reused in the mill and the remainder (ave 1500 l gal/min) sent to treatment before discharge to Mine Creek and Sturgeon Lake.

Water Treatment Plant

Treatment takes place in a building at the mill and consists of lime neutralization in two 10,500 l gal agitated reactors in series. The effluent then flows through two horizontal pipe flocculators (10 in. dia stainless steel), where flocculants are injected by metering pumps. Clarification takes place in a Pielkenrood plate clarifier system consisting of 8 plate pack units placed in two compartmented tanks. Sludge (4% solids) is drained from the clarifier via 6 in. dia pneumatic butterfly valves, activated by preset timers. The sludge then flows to a sludge tank, with most recycled using a 3 x 3 SRL pump to a 5280 Imp gal pre-mix tank. There, a lime slurry/sludge mixture is prepared for addition to the lime neutralization reactors.

Reagent preparation and handling consists of lime and polymer systems. Hydrated lime is taken from the concentrator lime storage bin using a variable speed screw conveyor (S.C.R. drive) which discharges into a slurry pot. There water is added at 30 l gal/min, and the resulting lime slurry is pumped to the lime slurry/sludge premix tank. Lime addition is controlled by adjusting the speed of the lime screw according to the pH in the feed to the flocculators. A dry polymer is prepared in a mixing tank, as a 0.1% solution, pumped to a holding tank, then metered to the pipe flocculators.

The instrumentation consists of feed water flow measurement and control, and pH measurement and control.

Tertiary Treatment Pond

- commenced operation in 1977
- located adjacent to the tailings pond
- approximately 3 days retention time at 1000 l gpm

- water from the reclaim pond is pumped to a liming station by a 2 stage Worthington vertical turbine pump
- lime is fed from a 30 ton silo by a variable speed screw conveyor with a SCR drive to maintain a pH of 10 - 10.5
- from the liming station water flows by gravity to the pond
- the precipitated metal flocs settle out in the pond
- the treated and settled water is pumped to the Bell River by a second 2 stage Worthington vertical pump
- the facility operates year round
- operation is best in winter as ice formed on the surface of the pond prevents turbulence and resuspension of the flocs
- plant operation is completely manual.

2.4 Noranda Mines Limited, Geco Division

Geco operates a mine and concentrator facility at Manitouwadge, Ontario, processing 4000 tons per day of ore containing copper and zinc. Acid mine water from underground and acidic seepage from the tailings disposal area totalling 670 I gal/min are treated by lime neutralization in a treatment plant located at the tailings area before discharge to Muskoka Ditch and Mose Lake.

The acidic effluents are collected in a 1,000,000 I gal holding pond, then pumped using rubber lined 30 HP Sala pumps to a aerated three compartment (17,000 Igal) lime neutralization reactor. Lime slurry is discharged into the first compartment, then the neutralized effluent overflows by gravity into the second and third compartments. Air (1200 cfm) is added at 12 psig from a 125 HP blower through an air distribution system (to oxidize iron from ferrous to ferris. The discharge flows through a 20 in. steel pipe where a polymer flocculant mixture is added, then into the centre well of a 75-foot diameter "Eimco" HRP reactor-clarifier. There, recirculated existing sludge and fresh influent are initially mixed using a submerged vertical updraft turbine. The sludge which settles is drawn to the centre of the clarifier by a rake system, where some drops

through a cone section under the clarifier, and is discharged on an automatic timed basis through an 8 in. rubber lined plug valve. The 2% sludge flows to a box, where it is pumped out using 15 HP Sala sludge pumps to the tailings area. The clarifier overflow is collected through a circular weir, flows by gravity to a 8700 I gal woodstave tank, then is discharged to Muskoke Ditch.

Reagent preparation and handling consists of lime and polymer systems. Hydrated lime used at the plant is stored in a 82 ton silo, then passes through a volumetric spiral screw feeder. There, water (5 I gal/min) and the lime are mixed together using a 1/3 HP mixer, before overflowing to an eductor system, which transports the 10% lime slurry to the aerated lime neutralization reactor. The polymer preparation/addition consists of two metering pumps, two static in-line mixing chambers and a polymer ageing coil. Liquid polymer leaving the coil is flash diluted, then transported to the injection point in the feed line to the clarifier.

The Geco water treatment plant is controlled using a microprocessor based programmable sequencer. The sequencer monitors such plant functions as neutralization pH and clarifier rake torque. It is programmed to automatically restart the treatment plant after power failures, generate alarms, and to temporarily shut the plant down on critical alarms to prevent plant upsets. the pH is monitored on a sample taken frjm the first compartment of the aerated neutralization reactor, with lime addition by the lime screw feeder controlled to maintain the appropriate pH.

3.0 SOURCES AND QUALITY OF WASTEWATER

The sources and quality of influents to Noranda Group treatment facilities are summarized in Table I. As indicated, the acidic waters originate mainly from mine drainage (both underground and open pit) and tailings ponds seepage. The main contaminants are heavy metals (Zn, Fe, Cu, Pb) with concentrations rangint from 0.01 mg/L to 1700 mg/L. The wastewaters can be grouped into three categories:

TABLE I
SOURCES AND QUALITY OF WASTEWATER

Location	Source	Flow (l gal/min)	Quality					
			pH	Zn (mg/L)	Fe (mg/L)	Cu (mg/L)	Pb (mg/L)	SO ₄ (mg/L)
MND-H	#12 Underground mine	335	2.6-3.0	1700	500-1200	5-12	3-7	12,000
	#12 Tailings decant, drainage, mine water	2900	3-5	50-250	10-200	0.01-3	5-20	300-1000
	#6 open pit and drainage	625	2.4-2.8	300-500	500-800	10-20	0.5-1.0	
mine water	Acid mine drainage.	400	3.5	530	865	0.26		
Metcobl	Underground mine water, mill tailings decant.	1000	5.8-6.9	10	1.5	0.06	0.06	
Uecu	Underground mine water, tailings dam seepage.	670	3.9	120	460	3.4	<0.05	3,000

- High metal, with concentrations exceeding 1000 mg/L and pH levels in the range of 2.5-3.5. This group includes BMS-M #12 and #6 and Mines Gallen mine waters.
- Medium metal, containing 100 to 1000 mg/L with pH in the range of 3 to 5. Waters from BMS-M #12 tailings area and from Geco fall in this group.
- Low metal, with levels of 10 to 100 mg/L and pH of 5.8 to 6.9 includes the waters from Mattabi.

4.0 QUALITY OF TREATED EFFLUENTS

The quality of effluents discharged from Noranda Group treatment facilities is summarized in Table II. In most cases, the pH is >9 and copper, lead levels are below 0.5 mg/L. Zinc and iron levels in some cases exceed 1.0 mg/L, due mainly to problems with solid/liquid separation, resulting in metal hydroxides being discharged.

5.0 PROCESS DATA REVIEW

Process data for Noranda Group lime neutralization facilities is summarized in Table III and can be reviewed with respect to unit operations.

5.1 Lime Reactors

Lime reactors are agitated tanks where wastewaters and lime are contacted resulting in an increase in pH, and precipitation of heavy metals. In most cases, agitation is by mechanical mixers, while air is added (if needed) to oxidize ferrous iron to the ferric form.

A review of Table III indicates total reactor retention times vary between 18.5 and 48 minutes. Total power was calculated by considering mixer horsepower and the air input, and ranges between 2.6 and 4.9 HP/1000 I gal of reactor volume.

TABLE II
QUALITY OF TREATED EFFLUENT

Location	pH	Zn (mg/L)	Fe (mg/L)	Cu (mg/L)	Pb (mg/L)	Suspended Solids (mg/L)	Comments
BMS-M							
#12 ANWTP	9-10	0.01-2	0.01-4	0.01-0.1	0.25		
#12 Lime Station	8-10	2-7	3-9	0.1	0.3-0.8		
#6 Water Treatment Plant	7.7-10	0.1-2.5	0.2-4	0.2	0.1-0.7		Pond Decant Water
Mines Gallen	6.5-9	0.45	0.75	0.04	0.16		
Mattabi	9.8	0.5	0.05	0.01	0.01		
Ceco	9.3	0.4	1.1	0.1	<0.01	11.8	

TABLE III
SUMMARY OF PROCESS DATA

Parameter	#12 AMWTP	BMS-H #12 Lime Station	#6 WTP	Mines Gullen	Martabi	Ceco
Average flow, L gal/min	335	2900	625	400	750	670
Lime Reactors						
Reactor Volume	2 X 8000 I gal	N/A	2 X 5800 I gal	2 X 9000 I gal	2 X 10,500 I gal	1 X 17,000 I gal (3 compartments)
Average reactor detention (min)	48	-	18.5	45	28	25
Reactor Agitation, Type and HP	Lightnin 10 HP	Lightnin 7.5 HP	Wemco 15 HP	N/A	Lightnin	-
HP/1000 I gal of reactor volume	1.25		2.6			-
Air Addition (cfm)	150 cfm @ 18 psi	-	-			1200 cfm @ 12 psig
CFM/1000 I gal of reactor volume	18.75					70.6
Total Power Input (air and agitator)	3.4		2.6	N/A		7.4
HP/1000 I gal of reactor volume						
Fluorimant Addition	2 sec flash mixing reactor	-	-	N/A	Flow reactor	Flash dil-polymer injected to pipe between reactor and clarifier
Clarifier						
Type and Size	Lamella, 2 plate packs effective surface of 2520 ft ²	Settling ponds	Settling Ponds	Lamella, 2 plate packs, effective surface of 2520 ft ²	Flotation, 8 plate packs, effective surface of 3600 ft ²	Flume 75 ft dia reactor clarifier
Overflow Rate, I gal/day ft ²	190	-	-	229	300	218
Reagent Addition						
Lime, type, lb/1000 I gal	Hydrated 67	Hydrated 9	Hydrated 42	Hydrated 18.5	Hydrated 0.38	Hydrated (1982) 10.2
Polymer type, mg/L	Dry, Aquafloc 462 15 mg/L	-	-	Dry, Parcel 156 N/A	Dry, Parcel 155 0.65 mg/L	Liquid Alchem 5 mg/L

5.2 Flocculant Addition

Flocculants are generally added to mixing reactors, with mixing times of 2 sec to 1.5 min. In one case, a flocculator mixing pipe is used, while at another facility, flocculants are injected to the pipe between the lime reactors and the clarifier.

5.3 Clarifiers

Wastewaters with precipitated solids are treated for solid-liquid separation before the effluent is discharged. Three facilities utilize plate-type clarifiers, with overflow rates ranging from 190 to 300 I gal/day ft², and one has a reactor clarifier (218 I gal/day ft²). Settling ponds are used at two lime stations for removal/disposal of solids.

5.4 Reagent Addition

Lime addition is related to the strength of wastewater. All the facilities use hydrated lime with dosing rates varying from 0.38 to 67 lb/1000 I gal wastewater treated. Polymer flocculants are used in the mechanical settling units, with almost all locations using dry polymers which are put into solution prior to use. No polymers are used in systems with settling ponds.

6.0 SOLIDS GENERATION AND DISPOSAL

Solids are generated in the lime neutralization facilities due to the precipitation of metal hydroxides, and CaSO₄. The density of the sludge solids is indicated in Table IV, with values ranging from 0.3 to 20% solids. Generally, the higher densities are associated with recycle of sludge from the clarifier to the lime reactor.

Sludges are disposed by a variety of methods. At treatment facilities located close to tailings ponds, the sludges are mixed in with the tailings (BMS #12 AMWTP, Geco). Mattabe generates a low sludge volume containing significant metal values, and blends this with its final

TABLE IV
SOLIDS GENERATION AND DISPOSAL

Location	Sludge Solids Density (%)	Sludge Solids Disposal	Comments
BMS-M			
#12 AMWTP	5	To tailings pond	No solids recycle
#12 Lime Station	1	Sludge ponds	No solids recycle
#6 WTP	1	Sludge ponds	No solids recycle
Les Mines Gallien	10-20	To solids disposal pond	High degree of recycle
Mattabi	4	To concentrate (small amount)	90% solids recycle
Geco	2	To tailings pond	No solids recycle

concentrate. At two lime facilities at BMS-M, sludge ponds are used for the settling and containment of sludges, with new ponds constructed as previous ones become full.

7.0 RESEARCH NEEDS

Based on the operation of its lime neutralization facilities, the Noranda Group recognizes needs for further research in the following areas:

1. The optimization of the lime neutralization process - with work aimed at such areas as effects of effluent concentration, sludge recycle and type of lime used on reaction kinetics, and lime requirements.
2. Solid-liquid separation - topics such as treatment efficiency of normal, reactor type, and Lamella type clarifiers; the effect of sludge recycle, and optimum design overflow rates should be considered.
3. The control of scaling in both lime reactors and clarifiers.
4. The problems of lime sludge disposal, especially in locations without mechanical clarification.
5. Process control appropriate to remotely-located facilities.
6. Treatment of materials not effectively controlled by lime addition (e.g. mercury, antimony, cyanide, molybdenum, ammonia).

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SULLIVAN MINING
TAILING MANAGEMENT STUDY

PART FIVE: REVEGETATION

1. RECLAMATION OBJECTIVE
2. PURPOSE OF REVEGETATION
3. REVEGETATION TECHNOLOGY
 - 3.1 Environmental Setting
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 - 3.4 Plant Growth Limiting Factors
 - 3.41 Lime Requirement
 - 3.42 Tailing Salinity Hazard
 - 3.5 Vegetation Establishment Growth and Quality
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4. OPERATIONAL REVEGETATION AND COSTS
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TAILINGS MANAGEMENT REPORT

PART FIVE: REVEGETATION

1. RECLAMATION OBJECTIVES

The reclamation objective at the Sullivan mine and concentrator is to stabilize and rehabilitate waste disposal and other disturbed land areas, wherever possible, by re-establishing a self-sustaining plant community of similar composition, productivity and usefulness as existed before disturbance or as exists on adjacent land.

2. PURPOSE OF REVEGETATION

Wherever possible, vegetation will be established to:

- a) stabilize tailing pond, waste dump and disturbed land surfaces against forces of wind and water erosion,
- b) control dust,
- c) minimize surface drainage contamination,
- d) minimize volume of mine drainage and tailing effluent requiring treatment prior to release to the St. Mary river with the ultimate objective of eliminating the need for drainage treatment altogether
- e) rehabilitate waste disposal sites to a productive land use,
- f) improve aesthetics of the area, and
- g) satisfy requirements of the Mines Act with respect to mined-land reclamation and the Waste Management Act with respect to air and water quality.

3. REVEGETATION TECHNOLOGY

A revegetation research program has been active on disturbed land and waste disposal sites at the Sullivan mine and concentrator since 1973.

The program has consisted of five basic types of investigation including:

1. characterization of disturbed land with respect to natural soil, vegetation, climate, present and future land use and potential capability for natural revegetation.
2. determining the suitability of mine and mill waste as growth media for plants. This is done by:
 - a) assessing natural revegetation, if any, on areas previously abandoned.
 - b) analyzing for those mineralogical chemical and physical properties which influence plant life and,
 - c) conducting growth room investigation to identify plant growth limiting factors.

3. REVEGETATION TECHNOLOGY (cont'd)

3. assessment of techniques for modifying waste materials to improve plant growth potential. This may include the addition of chemical and organic amendments, and modifying the physical state of waste disposal site by re-sloping, scarifying, covering with soil, etc.
4. selection of native and introduced plant species suitably adapted to local conditions, specifically plants with tolerance to climate and growth medium, and
5. monitoring vegetation grown on waste for nutrient imbalance and accumulation of potentially toxic metals.

Research progress is reported annually in the form of detailed reports submitted to the Senior Reclamation Inspector, B.C. Ministry of Energy, Mines and Petroleum Resources as per the terms and conditions of surface Work Permit M-74. In addition results of certain investigations have been presented at B.C. Mine Reclamation Symposia and field demonstration projects were viewed by participants of a tour held in conjunction with the sixth annual meeting of the Canadian Land Reclamation Association held in Cranbrook in August 1981.

Investigations related to the characterization and revegetation of Sullivan waste rock and tailing have also been conducted by graduate students and staff of the Soil Science Department, Faculty of Agriculture, University of British Columbia and are listed as follows:

1. Lavkulich, L.M. et al. 1975. Pedological Inventory of Three Sulfide Mine Areas in S.W. British Columbia.
2. Morton, J.W. 1976. The Physical Limitations to Vegetation Establishment of some Southern British Columbia Mine Waste Materials. M.Sc. Thesis.
3. Lavkulich, L.M. et al. 1977. Tailings Research Selected Mines British Columbia 1976 - 1977. Department Soil Science, U.B.C. Prepared for Ministry of Mines and Petroleum Resources, Victoria, B.C.
4. Robbins, J.M. 1978. Weathering and Microbial Activity in Sulfide Mine Tailings with Implications in Reclamation. M.Sc. Thesis.
5. Ames, S.E. 1981. The Reclamation of Sullivan Mine Iron Tailings. M.Sc. Thesis.

A summary of progress toward development of practical and effective revegetation techniques for siliceous and iron tailing disposal areas at the Sullivan concentrator is presented and includes pertinent information developed by Cominco's revegetation research and studies by the Soil Science Department at U.B.C. The summary includes a description of the environmental setting and climate of the tailing disposal area, a description of

3. REVEGETATION TECHNOLOGY (cont'd)

the chemical, physical and microbiological properties of the tailings and a discussion of alternative revegetation approaches being assessed. Quantity and quality of vegetation and changes in growth media properties have been

monitored regularly to compare the relative effectiveness of the revegetation techniques. Field experiments are, however, too small in scale to assess effectiveness in terms of achieving revegetation purposes listed in the previous section of this report.

3.1 Environmental Setting

The Sullivan concentrator and associated waste disposal areas are situated in a transition zone between the Purcell Mountain and Rocky Mountain Trench physiographic regions and two subzones of the Interior Douglas Fir biogeoclimatic zone, a wetter subzone lacking seral ponderosa pine and a drier subzone with seral ponderosa pine.

The concentrator, float rock pile and the north perimeter of the iron and siliceous tailings ponds are situated on deep medium to fine textured glacial till within the wetter subzone. Soil parent material was derived mostly from limestone and dolomite and is strongly calcareous. Topography is gently to moderately rolling with slopes of 5% to 15%. Soil development is predominantly luvisolic with significant brunisols.

The major area of the iron and siliceous tailing ponds is situated within the drier subzone with seral ponderosa pine. Tailing deposits are underlain by gravelly glacio fluvial deposits with a shallow surface veneer (<30cm) of fine to medium textured aeolean material. Soil parent material was derived from fine to coarse grained non-calcareous gravels. Topography is gently undulating with slopes of 2% to 5%. Soil development is predominantly chernozemic and brunisolic with some wet depressions in a generally well drained glacio-fluvial plain. Islands of gently to moderately rolling, deep medium to fine textured glacial till are situated south of the tailing ponds. These deposits were derived from limestone and dolomite bedrock and are strongly calcareous.

Undistributed land adjacent the concentrator has best physical capability for native range and currently sustains an open coniferous forest dominated by ponderosa pine with significant Douglas fir and trembling aspen and a ground cover of shrub, forb and grass species.

3.2 Climate

Moisture laden air from the Pacific dominates the weather of British Columbia at all seasons. Heavy rain and snow result from the ascent of moist Pacific air on the western slopes of the mountain ranges. Precipitation is light on the eastern slopes of the mountains and

3.2 Climate (cont'd)

semi-arid conditions prevail at the lowest elevations in parts of the interior valleys.

The main interior valleys in the southern part of the province have a north-south direction. These provide a path for masses of cold continental air from the north, particularly in winter, and for heated air from the southern plateaus of the U.S. in summer. This results in a wide annual temperature range.

Climatic conditions at Kimberley conform to this general pattern. On eastern slopes at the mine total annual precipitation averages 630 mm with approximately 50% occurring as snow. Near the concentrator at lower elevations in the valley total annual precipitation is lower averaging 409 mm with 42% as snow. Similarly, seasonal precipitation (May-Sept) averaged 217 mm at the mine compared to only 160 mm at the concentrator.

Mean annual temperature at the concentrator averaged 5°C. and ranged from 18°C. during July to -9°C. during January. Extreme maximum and minimum temperatures were 37°C and -40°C., respectively. Long term temperature data for the mine were not available, however, since initiation of the revegetation research program in 1972, mean annual temperature at the mine has been 1° to 2°C lower than at the concentrator while seasonal temperatures were 1° to 3°C lower.

Sunshine and wind conditions near the concentrator have been recorded as well. Annual hours of sunshine average 2077 which is 43% of the total possible. Wind averaged 185 km/day and were predominantly westerly i.e., 8.7% SW, 20.2% W, 13% NW. Periods of calm occurred 16.8% of the time. Westerly winds were the strongest averaging 5.7, 8.9 and 5.7 kph respectively for SW, W and NW directions.

Long term growing season climatic data was not available for the immediate vicinity of the concentrator, so data from Kimberley and Cranbrook airports is presented. Both airports are within the same physiographic region and biogeoclimatic zone as the concentrator and receive similar seasonal precipitation (Table 2.5). Growing season at Cranbrook averages 180 days and generally extends from April 15 to October 12. Growing degree days range from 1550 at Cranbrook to 1530 at Kimberley. The freeze free period averages 91 days however below freezing temperatures have been recorded every month during the growing season. Seasonal potential evapotranspiration approximate 540 mm resulting in a climatic moisture deficit of 380 mm.

3.3 Mineralogical, Chemical, Physical and Microbiological Properties

Sullivan concentrator tailings have been studied intensively by Cominco's Reclamation personnel and by the Department of Soil Science at U.B.C. Conventional soil analytical techniques were employed to

3.3 Mineralogical, Chemical, Physical and Microbiological Properties (cont'd)

describe mineralogical, chemical, physical and microbiological properties of siliceous and iron tailing. Samples were taken from the surface layer, i.e., 0 - 15 cm, at a number of locations within a dis-

posal area as well as from various depth intervals within a tailings profile. Samples were taken from tailing deposits in place for many years, from tailing deposited for less than two years and from freshly deposited tailings. In some cases the true origin of the tailing deposit was uncertain due to unrecorded changes in disposal patterns on spillage.

The various mineralogical, chemical, physical and microbiological properties of tailings were determined for several reasons including:

1. an attempt to describe tailings in terms normally used to describe soils and thus facilitate characterization of tailings using conventional soil-plant growth relationships.
2. to describe the variability of tailings within a disposal site, both horizontally over the tailings surface and vertically within the tailings profile,
3. to describe changes in tailings properties resulting from weathering and oxidation, and
4. to identify those properties which might limit plant growth on tailings.

In addition certain analytical techniques were applied in an attempt to quantify amendment requirements for improving tailings as a plant growth medium.

More recently tailings from in situ revegetation experiments have been sampled and analyzed regularly to monitor changes in certain properties with time following application of varying amounts of liming materials.

3.3.4 Mineralogical Composition

a) Siliceous Tailing

Siliceous tailings have been described as having the following mineralogical composition: pyrrhotite 20%, pyrite 2%, calcite 10-15%, quartz 5-10%, mica 0-5%, chlorite 0-5% and feldspar 2%.

Using X-ray diffraction on minus 200 mesh size fractions of partially oxidized siliceous tailings with pH 4.3, the following minerals were identified: quartz, kaolinite, illite, chlorite, pyrrhotite, gypsum and feldspar.

3.31 Mineralogical Composition (cont'd)

b) Iron Tailing

Iron tailing have been described as having the following mineralogical composition: pyrrhotite 85%, pyrite 5%, sphalerite 1%, galena 1% and quartz 5%. Using X-ray diffraction on minus 200 mesh size fraction of oxidized iron tailing analyzed from various depth intervals between the surface and 70 cm, the following minerals were identified: quartz, illite, chlorite, kaolinite, gypsum, jarosite and feldspar. pH of tailing samples ranged from 2.2 to 2.8. With exception of jarosite, the same minerals were identified in a sample from below the 70 cm depth. pH of this sample was 4.

3.32 Chemical Properties

Data describing certain chemical properties of siliceous and iron tailings are presented in Tables 3.1 to 3.4. Total elemental analysis was conducted at the Department of Soil Science, U.B.C.(5) using the method outlined by Buckley and Cranston¹ (Table 3.1). The samples were from two sites identified as "siliceous fresh" tailings and "siliceous - iron tailings". The high iron content and relatively low silica content of the fresh siliceous tailings, i.e., 45% and 2% respectively suggests the sample was freshly deposited iron tailings rather than siliceous tailings. Samples described as a siliceous - iron tailings mixture were sampled from various depth intervals between 0 and 70 cm, and below 70 cm, from a single profile within a long term deposit of siliceous tailings described as having a high iron content. The high pH and iron content of the samples from below 70 cm depth suggests weathering and oxidation had not progressed to the same extent as at shallower depths.

Data describing certain chemical properties including pH, total N, total S, organic matter content (i.e., % N x 20), cation exchange capacity and exchangeable cations are presented in Table 3.2. Sampling by the Department of Soil Science, U.B.C. included two profiles, one within oxidized siliceous tailings and the second within oxidized iron tailings. Samples of surface tailings from oxidized and unoxidized iron and siliceous tailings deposits were collected by Cominco. The data illustrate the relatively low values for total N, organic matter, cation exchange capacity and exchangeable cations characteristic of tailings as well as the variation in pH and total S content resulting from oxidation of iron sulphide minerals in both siliceous and iron tailings.

Buckley, D.E. and R.C. Cranston, 1971. Atomic absorption analysis of 18 elements from a single decomposition of alumino-silicate. Chem. Geol. 7: 273-284.

3.32 Chemical Properties (cont'd)

Available plant nutrients were determined by extracting tailings with chemical extractants normally used to determine the available nutrient content in agricultural soils(5). Data on the available (or perhaps more appropriately, extractable) N, P, K, Ca, Mg, Cu, Fe, Mn, Al, Zn and Pb are presented in Table 3.3. Available nitrogen, phosphorus and potassium were very low while calcium and magnesium appear to be adequate for plant growth. Extractable metal contents varied, with type of tailings, with sample site and with depth in the tailings profile. Differences in extractable metals between U.B.C. and Cominco samples were due to use of different chemical extractants. Relatively high concentrations of Fe, Mn, Zn, Pb and Cu were extracted from some samples of tailings.

The concentration and nature of water soluble salts contained in oxidized and unoxidized iron and siliceous tailings are described by data summarized in Table 3.4. Electrical conductivity, a parameter which relates soluble salt concentrations, tailings osmotic pressure and plant growth, varied from 3 to 22 mm hos/cm suggesting a wide range in salinity hazard from a slightly saline condition under which growth of sensitive plants may be restricted to a very strongly saline condition under which only a few tolerant plants can grow. Calcium and magnesium were the dominant cations in the tailings solution; however, soluble iron can be expected to be present in appreciable quantities. The low SAR values (sodium adsorption ratio) indicate no danger of physical problems developing from exchangeable sodium. Chloride and sulphate were the pre-dominant anions in solution.

3.3.3 Physical Properties

Data describing certain physical properties of siliceous and iron tailings are presented in Table 3.5. Tailings were composed primarily of sand and silt sized particles with clay content generally very low, but increasing as tailings weathered and oxidized. Textural class ranged from sandy loam to silt loam to loam for the samples analyzed. Distribution of sand and silt sized particles following deposition varied over the pond surface and with depth resulting in a wider range of textural classes than suggested by the data presented in Table 3.5. Soils which are predominantly sand and/or silt size particles are susceptible to wind and water erosion. Vertical variation in particle size can influence movement of air and water within the tailings deposit. The low clay content suggests very low adsorptive capacity for nutrients and water.

3.33 Physical Properties (cont'd)

Density of tailing particles ranged from 2.17 gm/cc for oxidized siliceous tailings to 3.85 gm/cc for fresh iron tailings. With oxidation, particle density appears to decrease from values considerably higher than an average soil particle, i.e., 2.65 gm/cc, to values considerably lower. Similarly, bulk density of tailings, which is an indirect measure of porosity and compaction, appears to decrease with oxidation to within the range of a normal silt loam soil i.e., 1.0 to 1.6 gm/cc. Root penetration problems often occur in soils with bulk density greater than 1.7 gm/cc. Total porosity of tailings approach values considered suitable for a plant growth medium, however aeration porosity at field capacity water content was high due, primarily to the relatively low water retention capacity of tailings.

Water retention capacity of selected samples of unoxidized and oxidized iron and siliceous tailings at 0.1, 0.9, 3 and 15 bars tension are presented in table 3.6. The difference in water content at 0.1 bar tension (field capacity) and 15 bars tension (permanent wilting point) represents the available water storage capacity (AWSC). Little water is available for plant growth above 3 bars tension, which is well below what is normally considered to be permanent wilting. This suggests that iron and siliceous tailings tend to be droughty. Unoxidized tailings appear to have lower water retention than tailings which have been deposited for many years and which have oxidized and weathered.

3.34 Variation in Tailings Chemical and Physical Properties

From the data presented in Tables 3.1 through 3.6, it becomes obvious that iron and siliceous tailing deposits are heterogeneous in terms of chemical and physical properties which affect plant growth. Variable distribution of the principal tailing size fractions and minerals during deposition and the subsequent oxidation and weathering of iron sulphide minerals create a deposit with variable characteristics not only on the surface or with depth but also with time, particularly during the first several years after deposition.

Data presented in Tables 3.7 and 3.8 illustrate changes which occur in siliceous and iron tailings with oxidation and weathering. Trends were similar for both types of tailings. Colour changed from gray-black to orange-brown. Texture becomes finer as the clay size fraction increases. This results in an increase in moisture retention at field capacity and permanent wilting, an increase in available moisture storage capacity and an increase in cation exchange capacity. Tailings pH decreases from the 6 - 6.5 range to near 2. The

3.34 Variation in Tailings Chemical and Physical Properties (cont'd)

The decrease in pH is attributed to the oxidation of pyrrhotite resulting in the generation of sulfuric acid. The decrease in pH may be correlated with a decrease in total sulphur content, a decrease in residual acidity and an increase in both active acidity and exchange acidity. Levels of extractable iron increase. Levels of extractable zinc and lead decrease, possibly the result of acid leaching or the formation of less soluble reaction products. Salinity increases critically with the breakdown of sulphides and subsequent formation and accumulation of soluble reaction products.

Tailing oxidation and the concomitant changes in physical and chemical properties can occur rapidly following deposition and exposure to atmospheric conditions. Within 24 months following deposition partial oxidation of a siliceous tailing deposit was evident through the surface 30 cm. Oxidizing tailings were heterogeneous in colour and texture. Hard impervious layers of varying thickness were present at variable depths below the surface. Tailing pH had decreased from near neutral at time of deposition to values ranging between 3.3 and 5.5 (1977 report). Tailing electrical conductivity varied widely from 4 to 22 mmhos/cm with an average of 6 mmhos/cm. Within 48 months pH of tailing treated with 100 mt/ha CaCO_3 had decreased to as low as 2.4 (1979 report). With peat moss added to the limed tailing pH averaged 3.2 with a range 2.4 to 4.7.

Sections of the iron and siliceous tailing deposits in place for as long as 30 years were sampled during May 1975 to assess variation in tailing properties after lengthy periods of exposure and oxidation (1975 report). Seventy-five samples, taken at a depth of 0 to 10 cm on a 200 m interval grid, were utilized to assess variation across the tailing deposit surface. Eleven profiles were described and sampled to determine variability with depth. Physical and chemical properties monitored included:

- a) description of physical structure,
- b) description of colour using the Munsell Colour Chart,
- c) pH using a 1:1 soil water ratio,
- d) electrical conductivity as determined on a saturation extract using a micro-cell and solubridge,
- e) active acidity expressed as the present lime requirement for neutralization to pH 8 and determined by the barium chloride-triethanolamine method,
- f) total sulphur determined by the leco combustion method,
- g) residual acidity expressed as the maximum CaCO_3 required to neutralize acid developed from sulphide-sulphur and determined by multiplying total sulphur content by a conversion factor of 31.24.

3.34 Variation in Tailings Chemical and Physical Properties (cont'd)

Using the orange-brown colour as an indicator of oxidation, depth of oxidation within the siliceous tailing deposit ranged up to 50 cm but varied considerably. Structure varied from granular on the surface to blocky at depths greater than 20 cm. Depth of oxidation within the iron tailing deposit ranged from 5 to 35 cm and appeared to be influenced by texture, cap formation and watertable depth. The surface consisted of a hard, but discontinuous, platy cap 2.5 cm to 5.0 cm thick. White salts precipitated on the underside of the cap. This platy cap expands and heaves forming dome-like structures. Near launders, where the tailing texture was coarser, small "flinty" plates were on the surface. In some areas, siliceous tailing had been deposited over the iron tailing resulting in a granular surface over the hard cap. A blocky structure formed below the cap. Unoxidized saturated iron tailing occurred below the blocky layer.

Mean and range values for pH, E_{Ce}, total S, active and residual acidity for surface samples of oxidized siliceous and iron tailing are presented in Table 3.9. The relatively narrow range of values for siliceous tailing is partly a reflection of the small size of the area sampled. However, the wide range in residual acidity suggests lime requirement may be extremely variable. All parameters ranged widely across the surface of the iron tailing deposit. Extreme conditions of acidity and salinity occurred throughout most of the iron tailing deposit (Table 3.10). An extremely variable but very high lime requirement and phytotoxic salt concentrations in combination with the hard, impervious surface suggest development of practical revegetation techniques for iron tailing per se may not be possible.

The chemical properties of siliceous and iron tailing varied with depth, however, the data presented suggest oxidation of variable degree occurred through the entire sampling depth (Tables 3.11 and 3.12) pH and E_{Ce} of siliceous tailing increased with increasing depth below the surface, but both parameters remained within a range considered phytotoxic throughout the entire 80 cm profile depth. A wider range of parameter values were observed within the iron tailing profiles, however, similar trends were evident. Mean values for pH, E_{Ce}, total S and residual acidity increased with depth and the range in values narrowed throughout the 45 cm profile depth. These data suggest that the depth of oxidation within iron tailing deposit was shallower than within siliceous tailing deposit due to formation of the hard, impervious cap at or near the surface. However, the resultant effect of oxidation in terms of plant growth was more severe within the iron tailing deposit.

3.35 Simulated Weathering of Iron and Siliceous Tailings

Simulated "natural weathering" of iron and siliceous tailings utilizing the Soxhlet weathering apparatus was studied at the Department of Soil Science, U.B.C. (6). The soxhlet procedure is basically a column leaching technique. The tailing samples were placed with the column and leached for 3 weeks with 0.3 N acetic acid or with distilled water. Temperature was regulated to $95 \pm 2^\circ\text{C}$. Fresh iron tailing and oxidized iron and siliceous tailing were leached for the required time period followed by total elemental analysis of the "weathered tailing". Leached tailing was extracted with various chemical extractants in an attempt to characterize the effect of simulated weathering on available nutrient release and to characterize the nature of weathering products. Elements released during weathering were detected by total elemental analysis of the tailing leachate.

Total elemental analysis of 0.3 N acetic acid and distilled water weathered tailings is presented in Table 4.1. The lower elemental content of weathered, unoxidized iron tailing relative to that of the original tailing suggest that most elements were being removed by the simulated weathering treatment. The elemental content of weathered tailings was similar for both leaching solutions. The acid nature of iron and siliceous tailings lowered the pH of the distilled water below the pH of the acetic acid solution resulting in acid weathering environments for both solutions. Weathered tailing was separated into "top" and "bottom" samples by removing the lower 5 cm away from the remaining upper portion of the sample for separate analysis. This was an attempt to detect any extreme vertical differences in elemental composition created by weathering. For most elements concentrations were slightly higher in the top sample. Exceptions included Ca and Pb in oxidized siliceous tailing and Na, K and Pb in oxidized iron tailing leached with distilled water.

A comparison of "available nutrient" concentrations extracted from weathered unoxidized iron tailing with concentrations extracted from the original unweathered tailing suggests that availability of Ca, Mg, K and Cu decreased and Zn, Fe, Pb, Cd and Co increased as result of weathering (Table 4.2). With exception of Pb, weathered oxidized iron tailing had lower available nutrient concentrations than weathered "fresh" iron tailing. In particular, oxidation resulted in a marked decrease in Fe and Zn concentrations.

As tailings weather, the original minerals are altered and secondary weathering products are formed as result of dissolution and precipitation. Weathering products in soils are classified by extracting Fe, Al, Si and Mn using a suite of chemical extractants including sodium pyrophosphate, acid

3.35 Simulated Weathering of Iron and Siliceous Tailings (cont'd)

ammonium oxalate and citrate-bicarbonate-dithionite. Sodium pyrophosphate extracts Fe and Al (Si, Mn) that is in a very fine amorphous state. Acid ammonium oxalate extracts finely amorphous compounds as well as the more stable hydrous oxides. Citrate-bicarbonate-dithionate extracts both amorphous forms and the more permanent crystalline oxides of Fe and Al (Si, Mn).

Concentrations of Fe, Al, Si and Mn extracted from weathered and unweathered tailings by the three extractants are presented in Table 4.3. Since with few exceptions Al, Si, and Mn conform to a similar extraction pattern as Fe, i.e., $CBD > AAO > SP$, only extractable Fe patterns are discussed. In the fresh, unweathered samples of iron tailing, secondary Fe compounds were predominantly amorphous hydrous oxide with significant Fe as fine amorphous compounds and crystalline oxides. A similar pattern occurred following simulated weathering with distilled water. However, fine amorphous Fe compounds predominated following weathering with 0.3 N acetic acid. After years of natural weathering and oxidation, secondary Fe was present primarily as amorphous hydrous oxide and crystalline oxides, probably as coatings on tailing particles. After simulated weathering with either acetic acid or distilled water the crystalline oxides predominated. Similar patterns were observed with oxidized siliceous tailing, with secondary Fe present primarily as crystalline oxides with significant amorphous Fe hydrous oxides. Following simulated weathering crystalline oxides predominated with amorphous hydrous oxides possibly being removed by leaching.

The chemical composition of leachate collected after 1 and 3 weeks of simulated weathering is presented in Table 4.4. Generally concentrations of elements were higher after the first week due to the relatively easy removal of the more soluble constituents. It is of interest to note that the pH of the distilled water leachate was generally lower than the pH of the acetic acid leachate. Fe was present in the highest concentration in leachates from all tailings. Similarly Mg, Ca and K were present in all leachates at medium concentrations. Medium concentrations of Mn were released from unoxidized iron tailing. Oxidation and natural weathering of iron tailing resulted in increased concentration of Al, Si, Zn, Cu and Pb and decreased concentrations of Ca, Mg and K. Leachate from oxidized siliceous tailing contained significant concentrations of Si, Al, Zn and Mn in addition to Fe, Mg, Ca and K.

3.36 Microbiological Characteristics of Iron and Siliceous Tailings

Microbiological characteristics of surface samples of iron and siliceous tailings in varying states of oxidation and natural weathering were investigated by Robbins (7). An important objective of Robbins thesis was to identify and characterize the role of microorganisms in the oxidation and weathering of sulphide tailings. A copy of Robbins thesis is on file with Cominco's Reclamation Agronomist. A brief summary of the study and results is presented.

One hundred and twenty samples from the tailings deposit surface were analyzed for microbial populations as well as certain chemical, mineralogical and physical parameters. Microbial groups enumerated included iron bacteria (Thiobacillus ferrooxidans), sulphur bacteria (Thiobacillus species), acid tolerant fungi and acid tolerant heterotrophic bacteria. Chemical parameters included sulfur forms, organic matter, pH, electrical conductivity, moisture content and major water and acid extractable cations. Sulphur forms analyzed for included iron monosulfides, total oxidizable sulfur (excluding iron monosulfides) elemental sulfur, water extractable sulfate and acid extractable sulfate. The water and acid extractable cations included Fe, Al, Ca, Mg, K and Na. Mineralogically the samples were analyzed qualitatively for crystalline sulfur and iron minerals as well as clay minerals. Physical properties included Munsell soil colour, texture and structure.

The most prevalent groups of micro-organisms in siliceous tailings were acid tolerant fungi and sulfur oxidizing bacteria with frequencies of occurrence of 93% and 70%, respectively. Acid tolerant heterotrophic bacteria and iron oxidizing bacteria were found in only 30 and 13% of the samples respectively. A symbiotic relationship between acid tolerant heterotrophic bacteria and sulfur oxidizing bacteria was indicated on basis of population associations.

Iron tailings with $\text{pH} > 2.5$ had a higher frequency of occurrence for sulfur bacteria (88%), acid tolerant heterotrophic bacteria (58%) and iron bacteria (58%) than siliceous tailings. Acid tolerant fungi occurred in 77% of samples. A symbiotic relationship between iron bacteria and the acid tolerant heterotrophic bacteria was indicated.

Acid tolerant heterotrophic bacteria and fungi occurred in 67% and 81% of iron tailing samples with $\text{pH} < 2.5$. Iron and sulfur bacteria were less frequent, being present in 28% and 19% of samples respectively.

3.36 Microbiological Characteristics of Iron and Siliceous Tailings (cont'd)

Fungi, which occurred most often, were not correlated with the other groups in either iron or siliceous tailings. Fungi populations appeared to increase with weathering perhaps reflecting an increased colonization of the tailing over time.

Four species of the sulphur bacteria, genus *Thiobacillus* were identified including *T. thioparus*, *T. neapolitanus*, *T. thiooxidans* and *T. ferrooxidans*. A succession of thiobacilli from *T. thioparus* to *T. neapolitanus* and ultimately to *T. thiooxidans* and *T. ferrooxidans* occurred as the pH decreased in the iron and siliceous tailings. In iron tailing with pH>2.5, *T. Thioparus* predominated at high pH values and *T. Thiooxidans* at low pH, with occurrence frequencies of 27 and 20% respectively. *Thiobacillus neapolitanus* was the most prevalent sulfur bacteria in the siliceous tailings, occurring in 43% of the samples. By comparison, *T. thioparus* and *T. Thiooxidans* were only present in 3 and 10% of the samples. *Thiobacillus ferrooxidans* occurred in 42% of iron tailing samples with pH>2.5 and 28% of samples with pH<2.5.

Tailing oxidation reactions and reaction products were described based on changes observed in chemical and mineralogical properties. The initial oxidation of Fe^{+2} from iron monosulfides, particularly pyrrhotite, to yield amorphous Fe oxyhydroxides was rapid. Concomitant with the oxidation of Fe^{+2} , sulfide was oxidized to elemental S and to some extent to other partially oxidized sulfur forms including polysulfides, thiocyanates, thiosulfate and polythionates. Sulfate produced from the oxidation of elemental sulfur through a series of intermediates, occurs mainly as gypsum in basic to slightly acid samples. At more acid pH values, gypsum was less evident and K-jarosite became the predominant sulfate containing mineral.

Texture, structure and colour changed with oxidation and weathering. Overall texture changed from an average of silt loam to finer textures as jarosite was formed. This trend was more pronounced in iron tailing. Structure changed from granular to blocky with oxidation of siliceous tailing. In iron tailing, platy and often massive structures occurred in the highly weathered samples. Colour, as represented by hue values and chroma, increased as pH decreased and sulfate increased, which would be expected as jarosite content increased.

3.4 Plant Growth Limiting Factors

Oxidation and weathering transform siliceous and iron tailings from relatively non-toxic to extremely toxic media for growth of plants. In a reduced state, both tailing materials were neutral to medium acid in reaction, slightly to moderately saline, devoid of decomposing plant residues and deficient in plant available N, P and K with a very low cation exchange capacity and low exchange acidity. Plant available moisture storage capacity varied with texture but ranged 10 to 15% for tailings in the silt loam range.

Following deposition and exposure, rapid oxidation of pyrrhotite results in development of an extremely acid reaction and accumulation of high concentrations of soluble salts, both phytotoxic conditions. Available nitrogen, phosphorous and potassium remain low and within the deficiency range. Available water storage capacity increased with oxidation particularly for iron tailing.

Oxidation of iron tailing resulted in the formation of a hard, impervious platy layer over 85% of the tailing disposal area surface. This hard, impermeable cap would prevent infiltration of air and water restrict root growth and prevent effective incorporation of amendments such as lime and fertilizer. In addition, saturated unoxidized iron tailing underlying the oxidized zone have been described as thixotropic with insufficient strength to support heavy equipment. Unlike iron tailing, oxidized siliceous tailing do not develop an impermeable layer at or near the tailing deposit surface.

The severity of plant growth limiting factors vary with the type of tailing, as result of tailing segregation during deposition and with time.

3.41 Lime Requirement

The phytotoxic effects of extreme acidity can be alleviated by application of appropriate quantities of liming materials. Analytical, incubation, growth room and in situ field plot techniques have been applied in an attempt to determine lime requirement of siliceous and iron tailings.

Initial attempts involved use of the Barnhisel and Massey² incubation technique and the more convenient and less time consuming BaCl_2 - triethanolamine technique. Based on the latter technique lime requirement of oxidized siliceous and oxidized iron tailings was 112×10^3 and 248×10^3 ppm CaCO_3 respectively. In contrast fresh siliceous tailings had a CaCO_3 equivalent of 400 ppm.

Barnhisel, R.I. and H.F. Massey, 1969. Chemical, mineralogical and physical properties of eastern Kentucky acid-forming coal spoil materials. Soil Sci. 108: 367-372.

3.41 Lime Requirement (cont'd)

Lime requirement values for oxidized siliceous and iron tailings were subsequently confirmed in growth room studies. Incorporation of 112×10^3 ppm CaCO_3 , as dolomitic limestone, maintained oxidized siliceous tailings pH near neutral through a combined 86 week growth and fallow cycle. In comparison, with 56×10^3 ppm CaCO_3 , pH was maintained within the 4.2 to 4.5 range. Similarly, with oxidized iron tailing 248×10^3 ppm CaCO_3 maintained pH between 6.2 and 6.7 through the 86 week period while with 124×10^3 ppm CaCO_3 pH dropped to the 3.3 to 3.7 range.

The results of these studies suggest that the BaCl_2 - TEA technique may have potential as a technique for estimating lime requirement of tailings which have oxidized and weathered for many years but is not suitable for fresh or recently deposited tailings which are actively oxidizing. An incubation technique was used to estimate lime requirement of recently deposited siliceous tailing. Coarse (sl) and medium (sil) textured tailings mixed with 0, 70, 90, 110, 130 and 150×10^3 ppm CaCO_3 were incubated for 66 months at ambient temperature in a laboratory. Tailing moisture content varied between field capacity and drier. In addition to texture the tailing varied slightly in total S, CaCO_3 equivalence and theoretical lime requirement (i.e., total S $\times$ 31.25). Sandy loam tailing was 8.7% S and 5.2% CaCO_3 with a theoretical lime requirement of 222×10^3 ppm CaCO_3 . Silt loam tailing was 8.6% S and 3.5% CaCO_3 with a theoretical lime requirement of 234×10^3 ppm CaCO_3 . At the completion of the 66 month incubation period sandy loam tailing mixed with 130×10^3 ppm CaCO_3 had a pH of 7 compared to 2.8 for the 110×10^3 ppm CaCO_3 rate. A slightly lower lime requirement was indicated for the silt loam tailing with 110×10^3 ppm CaCO_3 rate. However, a drop of 0.4 pH units during the last 12 months of the study suggests that oxidation and lime consumption was not complete. Higher rates of lime than those indicated will be required to maintain recently deposited siliceous tailing within a reaction range tolerated by plants. How much higher has yet to be determined. A field study initiated in 1979 to develop this information was terminated after two growing seasons due to construction of a lift on the tailing dyke.

A field study to confirm oxidized siliceous tailing lime requirement was initiated in 1980. Agricultural grade hydrated lime (90%) and dolomitic limestone (10%) were spread at rates equivalent to 60, 90 and 120 t/ha - 15 cm and incorporated by rotovator. Based on a bulk density of 1.3 g/cc for oxidized siliceous tailings these rates were equivalent to 30, 45 and 60×10^3 ppm CaCO_3 , substantially lower than the lime requirement indicated by the BaCl_2 - TEA and growth room studies. The low

3.41 Lime Requirement (cont'd)

rates were selected on the basis of early results of a preliminary small scale field plot initiated in 1978 which demonstrated that 98 t/ha - 15 cm CaCO_3 (50×10^3 ppm CaCO_3) equivalent was sufficient to sustain vegetative growth on oxidized siliceous tailings and maintain tailing pH near neutral. Since 1980 pH of tailings treated with 98 t/ha CaCO_3 has decreased from 7.5 to 3.4.

During the third growing season after liming, oxidized siliceous tailing pH varied widely from 1.6 to 7.8. Mean pH varied with lime rate as follows: 3.4, 4.4 and 5.4 for 60, 90 and 120 t/ha - 15 cm, respectively. A similar range in pH was observed within each lime rate; however, the 120 t/ha - 15 cm rate had the greatest frequency of samples with pH>5 i.e. 60%. Only 40% and 20% of samples from the 90 and 60 t/ha - 15 cm ratio has pH>5. These preliminary results suggest a variable lime requirement greater than 120 t/ha - 15 cm for most of the oxidized siliceous tailing deposit; perhaps approaching that indicated by the BaCl_2 - TEA technique i.e. 220 t/ha - 15 cm. Again referring to the small scale study initiated in 1978, 195 t/ha - 15 cm CaCO_3 equivalent has maintained tailing pH on average at 7.3 while vegetative growth continues to flourish.

Field experience with liming oxidized iron tailings has been limited to a single small scale study initiated in 1978. In this case pH of tailings 6 growing seasons following application of 360 t/ha - 15 cm CaCO_3 had decreased to 2.7. A 450 t/ha - 15 cm CaCO_3 application would be equivalent to the 248×10^3 ppm CaCO_3 .

While not definitive with respect to the actual amounts required, laboratory, growth room and field studies have demonstrated a need for extremely large quantities of liming materials to maintain oxidized siliceous and iron tailing within a pH range tolerated by most plants over the short term i.e. 5 years. Long term requirements remain unknown. Similarly, recently deposited siliceous tailings require recently deposited siliceous tailings require large amounts of lime to buffer acid generated during oxidation of pyrrhotite following deposition. How much lime is required has yet to be determined.

3.42 Tailing Salinity Hazard

The salinity hazard classification for agricultural soils is as follows:

3.42 Tailing Salinity Hazard (cont'd)

<u>ECe</u> (mmhos/cm)	<u>Hazard</u>	<u>Description</u>
0 - 2	non-saline	salinity effects negligible
2 - 4	very slightly saline	yields of sensitive crops may be restricted
4 - 8	moderately saline	yields of many crops re- stricted
8 - 16	strongly saline	only tolerant crops yield satisfactorily
16 +	very strongly saline	only a few tolerant crops yield satisfactorily

Based on a similar classification for siliceous and iron tailings salinity hazard can vary widely from very slightly saline to very strongly saline. Fresh tailings are generally very slightly saline, but with oxidation and weathering very strongly saline conditions develop rapidly. Within 24 months after deposition ECe of siliceous tailings varied from 3.5 mmhos/cm to 31 mmhos/cm. Similarly, in a growth room study unoxidized siliceous tailing increased from 3 mmhos/cm to 34 mmhos/cm after a combined plant growth and fallow period of 86 weeks. Tailings which have oxidized and weathered for many years have a more variable and more severe salinity hazard than freshly deposited tailings. ECe of 69 surface samples from an oxidized iron tailing deposit ranged from 2 to 64 mmhos/cm and averaged 13 mmhos/cm. More than 60% of the samples had ECe of 10 mmhos/cm or higher; 37% had ECe greater than 15 mmhos/cm. Oxidized siliceous tailings ECe averaged 6 mmhos/cm but ranged from 4 to 10 mmhos/cm for a fewer number of samples.

In field studies, tailing salinity hazard was observed to vary following incorporation of liming materials. Lime application rate and time influenced tailing ECe values. Within three months of incorporating up to 400 t/ha - 15 cm CaCO₃ with recently deposited siliceous tailing, ECe varied from 5 to 51 mmhos/cm. Mean ECe for 100, 200, 300 and 400 t/ha - 15 cm lime rates were as follows: 14, 26, 37 and 35 mmhos/cm. After two growing seasons ECe decreased but still varied with lime rate averaging 7, 4, 4 and 9 mmhos/cm respectively for 100, 200, 300 and 400 t/ha - 15 cm. The range in ECe values also narrowed to 3 to 14 mmhos/cm.

Similar trends were observed with siliceous and iron tailings which have oxidized and weathered for many years. Application of 293 and 390 t/ha - 15 cm CaCO₃ increased oxidized siliceous tailing ECe to 9 and 13 mmhos/cm respectively during the first growing season but ECe decreased to within the 3 to 6 mmhos/cm range during the subsequent 5 growing seasons. With oxidized

3.42 Tailing Salinity Hazard (cont'd)

iron tailing application of up to 360 t/ha - 15 cm CaCO_3 did not raise ECe appreciably during the first year, however ECe of tailing limed at the low rate of 90 t/ha - 15 cm increased to 10 during subsequent years. This increase in salinity hazard accompanied a rather sharp decrease in pH from 6.5 to 2. Average ECe for oxidized siliceous tailing limed in 1980 with 60, 90 and 120 t/ha - 15 cm CaCO_3 varied between 5 and 6 mmhos/cm. Maximum ECe recorded during three growing seasons was 13 mmhos/cm. Once again the highest ECe values were with samples having very low pH in the order of 2.

Leaching, incorporation of organic matter and planting salt tolerant plant species are cultural techniques most often used to ameliorate saline soils. Growth room experiments were conducted between 1973 and 1975 to assess effects of leaching and organic matter additions on the salinity hazard of oxidized siliceous and iron tailings as well as actively oxidizing fresh siliceous tailings. Grasses of varying salinity tolerance were grown on limed tailings either leached with water or mixed with sewage sludge.

Leaching improved growth of reed canary grass and tall wheat grass on oxidized siliceous tailing by maintaining tailing salinity within the slightly to moderately saline range. With no leaching yield of reed canary grass and tall wheat grass was only 30% and 51% of yield on a normal soil and tailing ECe increased to 26 mmhos/cm. With leaching relative yield increased to 85% and 87% for tall wheat grass and reed canary grass respectively.

Neither grass specie established on unleached oxidized iron tailings. Leaching reduced salinity hazard sufficiently so that relative yield increased to 48%. Tailing ECe increased from 30 to 43 mmhos/cm during the 20 week growth period. Leaching 3 times during the growth period reduced ECe to 25 mmhos/cm.

Application of up to 200 t of sewage sludge did not reduce the salinity hazard of oxidized siliceous and oxidized iron tailings. Leaching was required to reduce salt concentrations in tailings mixed with sewage sludge to levels tolerated by salt tolerant tall wheat grass.

With fresh actively oxidizing siliceous tailing plant growth conditions deteriorated rapidly during the 54 week growing period. Only tailing mixed with 125 ton dolomitic limestone and 200 ton sewage sludge sustained plant growth throughout the entire study period. Addition of sewage sludge to unlimed tailings had no beneficial effect but sustained grass growth for a longer period on limed tailing. It was concluded that

3.42 Tailing Salinity Hazard (cont'd)

incorporation of large amounts of lime and sewage sludge slowed development of extreme acidity and accumulation of soluble salts but did not prevent deterioration of growing conditions and plant growth.

Incorporation of a 7.5 cm thick layer of peat moss with recently deposited siliceous tailings limed with 100, 200, 300 and 400 t/ha - 15 cm CaCO_3 , reduced tailing E_{ce} by 1 to 5 mmhos/cm with the greatest reduction occurring in tailings having the highest salinity hazard. Incorporation of peat moss also reduced tailing pH by 0.5 to 1.5 units while increasing tailing saturation percentage from 40% to 112%.

3.5 Vegetation Establishment, Growth and Quality

3.51 Growth Room Studies

Cultural techniques designed to mitigate the adverse effects of extreme acidity and salinity on revegetation of oxidized siliceous and iron tailings were applied successfully in a growth room environment. In review application of 112 tonnes of dolomitic limestone per 1000 tonnes of tailings effectively neutralized the acid reaction of oxidized siliceous tailings and maintained a reaction suitable for growth of tall wheat grass, a salt tolerant grass species. Salt concentrations in limed, oxidized siliceous tailings were too high for less tolerant grass species to grow satisfactorily. However, leaching one time with one cm. of water per cm depth of tailings reduced salt concentrations to levels tolerated by all but salt sensitive species. With oxidized iron tailings, growth room studies demonstrated that large quantities of liming materials and excessive leaching with water were necessary to sustain growth of a salt tolerant grass. For example, 248 tonnes of dolomitic limestone per 1000 tonnes of tailings in combination with leaching three or more times with 1 cm of water per cm depth of tailings were required to produce a cumulative relative yield of 48% with tall wheat grass.

~~3.51~~ Growth Room Studies

Land surface covered by oxidized siliceous tailings is small relative to the area covered by recently deposited, unoxidized siliceous tailing. Unfortunately attempts to sustain vegetation on unoxidized siliceous tailings have been less successful in growth studies to date. Extremely acid and saline conditions developed rapidly in unamended, unoxidized siliceous tailings causing death to grass species established on the tailings material. Incorporation of large amounts of dolomitic limestone and sewage sludge slowed development of the acid

3.51
35.1

Growth Room Studies (cont'd)

reaction and minimized accumulation of soluble salts, but did not prevent deterioration of growing conditions and of plant growth. Very large quantities of dolomitic limestone (125 tonnes/1000 tonnes of tailings) and sewage sludge (200 tonnes/1000 tonnes of tailings) applied in combination were necessary to sustain tall wheatgrass growth (49% relative yield) throughout the experiment. Vegetation produced on siliceous tailings - sewage sludge - dolomitic limestone mixtures accumulated high concentrations of zinc. Zinc concentrations increased with increasing sewage sludge rates.

3.52 Field Studies

Two approaches for revegetating iron and siliceous tailings are being assessed on site including:

1. liming tailings to pH range tolerated by agronomic legume and grass species and applying fertilizer to sustain plant growth and
2. covering tailings with either glacial till overburden or less toxic wastes including float rock and gypsum, a solid waste produced during phosphoric acid manufacture at Cominco's fertilizer operations in Kimberley.

Float rock is being used in iron tailings revegetation to provide a safe working surface for equipment spreading overburden or gypsum. Float also functions as a barrier to prevent contamination of soil and gypsum with acid salts from the tailings.

3.52.1 Oxidized Siliceous Tailing Revegetation

1. Liming

Two field studies using agricultural liming materials to maintain a tailing reaction suitable for vegetation are currently being monitored. In a small scale study (Project SC-3-78) oxidized siliceous tailing were limed with 100, 200, 300 and 400 t CaCO_3 per ha - 15 cm. Agricultural hydrated lime was applied in June, 1978 and incorporated using a rototiller. On April 23, 1979 a seed mixture composed of tall wheatgrass (30%), crested wheatgrass (30%), Canada bluegrass (5%), hard fescue (5%), creeping red fescue (7.5%), red top (2.5%) and birdsfoot trefoil (20%) was sown on limed tailings at 100 kg/ha. Fertilizer was applied prior to seeding at a rate equivalent to 50 kg/ha N, 500 kg/ha P_2O_5 and 100

3.52.1 Oxidized Siliceous Tailing Revegetation (cont'd)

kg/ha K_2O . A maintenance application of 50 kg/ha N, 250 kg/ha P_2O_5 and 100 kg/ha K_2O was made in April 1980. The equivalent of 50 kg/ha N, 64 kg/ha P_2O_5 and 40 kg/ha K_2O has been applied as maintenance in spring of 1981, 1982 and 1983. On April 20, 1980, 40 mammoth wildrye sprigs were transplanted on each lime rate treatment. On May 12, 1982 1 - 0 seedlings of Douglas fir, lodgepole pine, engelmann spruce and ponderosa pine were planted on the revegetated treatments.

Vegetative cover, species composition mammoth wildrye and conifer survival as well as tailing pH and ECe were monitored periodically. Monitoring data are summarized in Tables 5.1, 5.2 and 5.3. Trends observed since establishment are discussed.

a) Vegetation

Seedling establishment was poor in 1979 due to very dry and warm weather for several weeks following seeding. This resulted in less than satisfactory vegetative cover in 1980 (Table 5.1). Crested wheatgrass and tall wheatgrass were the main species establishing in 1979 and dominated vegetative cover in 1980. However, dense populations of grass and birdsfoot trefoil seedlings emerged during the 1980 growing season which resulted in an improved plant cover the following year. By 1981, the third growing season, a satisfactory plant cover was established on tailing limed with 98, 195 and 293 t/ha-15 cm $CaCO_3$. Vegetative cover and biomass were similar with the two lower rates i.e. 46 to 49% vegetative cover and 3600 kg/ha biomass. Species composition varied, however, with tall and crested wheatgrasses dominant with the low lime rate while crested wheatgrass, red top and birdsfoot trefoil dominated vegetation with the higher lime rate. The relatively poor vegetation establishment on tailing limed with 390 t/ha-15cm $CaCO_3$ was attributed to the strongly alkaline reaction which persisted through the second growing season.

More than 90% of mammoth wildrye transplants survived the first two growing seasons. Growth was excellent and plant population increased as new shoots formed from rhizomes. The largest

3.52.1 Oxidized Siliceous Tailing Revegetation (cont'd)

increase in mammoth wildrye populations was on the low lime treatment.

In 1981 grass vegetation samples contained elevated concentrations of Pb and Zn when compared to levels considered normal for grasses growing on uncontaminated soil i.e., 10 ppm Pb and 30 ppm Zn. Metal concentrations were highest in vegetation growing on tailings limed at the low rate averaging 113 ppm Pb and 73 ppm Zn.

By 1981 pH of tailings limed with the low rate had decreased to 4.8 while tailings limed at higher rates ranged from near neutral to moderately alkaline. Re-development of this strongly acid reaction was accompanied by a decrease in vegetative cover which continued through the 1983 growing season. Tall and crested wheatgrass population has decreased but surviving plants were sustaining satisfactory growth in spite of a pH drop to 3.4 in 1983. Mammoth wildrye populations and cover continued to increase on this very strongly acid growth medium. Tailing limed with 195 and 293 t/ha-15 cm CaCO_3 maintained a moderately alkaline reaction through 1983 and sustained satisfactory growth and cover of a diverse plant community dominated by red top and Canada bluegrass with significant creeping red fescue, mammoth wildrye, crested wheatgrass and tall wheatgrass and minor amounts of birdsfoot trefoil.

Conifer survival after two growing seasons averaged 44% but varied with lime rate and specie (Table 5.3). Highest seedling mortality was on tailing limed at the low rate. Ponderosa pine mortality was highest among species. Surviving seedlings appeared healthy but growth was poor.

b) Tailing pH and ECe

With 195 t/ha-15 cm CaCO_3 tailing pH was maintained within a moderately alkaline to near neutral range through the first 5 growing seasons (Table 5.2). The very strongly alkaline reaction which peresisted through the first two growing seasons in tailings limed at 293 and 390 t/ha may have limited seedling establishment. The low rate of 98 t/ha was not adequate to maintain tailing within a suitable pH range beyond 2 growing seasons.

b) Tailing pH and ECe (cont'd)

ECe of limed tailing has remained within the slightly to moderately saline range throughout 5 growing seasons. ECe increased temporarily during the first few months following addition of the two higher rates but decreased to near normal by the beginning of the first growing season.

A pilot scale liming demonstration (Project SC-2-80) was initiated on oxidized siliceous tailings during the 1980 growing season. Liming materials were applied to 1.5 ha of oxidized siliceous tailings. Lime was applied at three rates 60, 90 and 120 t/ha-15 cm CaCO_3 , in the form of agricultural hydrated lime (90%) and dolomitic limestone (10%). Liming materials were spread manually and incorporated with the surface 15 cm. depth of tailings using a 120 cm wide rotovator powered by a Ford 1700 tractor. The 90 and 120 tonne rates were applied August 19. The 60 tonne rate was applied approximately two months later on October 15th. Revegetation included:

1. transplanting plugs of mammoth wildrye and tufted hairgrass, two grasses which sustain satisfactory growth on strongly acid soil in the Trail, B.C. area, onto limed tailings on October 6th, 1981.
2. seeding two legume - grass mixtures onto limed tailings on May 11th, 1982. Seed mixtures were composed of the following species:

Mix 1 - birdsfoot trefoil 20%, creeping red fescue 20%, Canada bluegrass 6%, crested wheatgrass 50% and red top 4%.
Mix 2 - birdsfoot trefoil 50% and hard fescue 50%. The mixtures were seeded at 50 kg/ha using a brillion seed drill mounted on a Ford 1900 tractor.
3. planting 100 seedlings each of ponderosa pine, lodgepole pine and Douglas fir within each lime rate treatment. The conifer seedlings were planted on May 11th, 1982.

In preparation for seeding and planting the equivalent of 500 kg/ha P_2O_5 and 100 kg/ha K_2O were broadcast in the form of 0-45-0 and 0-0-60

3.52.1

Oxidized Siliceous Tailing Revegetation (cont'd)

and incorporated using a rotovator powered by a Ford 1900 tractor. Fertilizers were applied October 6th, 1981. Additional fertilizer in the form of 11-55-0 was broadcast and incorporated on May 11th, 1982 at a rate equivalent to 50 kg/ha N and 250 kg/ha P_2O_5 . A slow release fertilizer pellet was also placed in the planting hole of each conifer seedling. A maintenance application of 52 kg/ha N, 64 kg/ha P_2O_5 and 40 kg/ha K_2O was made in May 1983.

Limed and unlimed tailings were sampled in late June 1982 and 1983 to determine pH and ECe. Vegetation establishment was monitored in late June 1983 by assessing vegetative cover, species composition and biomass as well as transplant and conifer survival. Results are summarized in Tables 5.4, 5.5 and 5.6

An old launder traversed the south end of the experimental site and the various lime rate treatments. Coarser textured tailings were deposited close to the launder. Finer textured tailing slimes flowed north settling on the north half of the plot. Segregation of the various particle size fractions during deposition influenced lime requirement and vegetation establishment (Table 5.4). Vegetation established satisfactorily on 82% of sample sites on the south half compared to only 45% on the north half. Tailing pH was also higher averaging 4, 5.7 and 6.1 for 60, 90 and 120 t/ha $CaCO_3$ respectively, on the south half compared to 2.1, 2.6 and 4.4 for similar lime rates on the north half. ECe was 2 to 3 mmhos/cm lower on the south half of the plot however the salinity hazard was generally within the moderate range, i.e. 4-8 mmhos/cm, throughout the entire plot area. Conifer, mammoth wildrye and tufted hairgrass transplant survival rates were also higher at the south end (Table 5.5).

Preliminary results indicate that dense grass-legume vegetation together with conifers can establish and grow satisfactorily on oxidized siliceous tailings treated with sufficient lime to maintain tailings within a reaction range suitable for those types of plants. How much lime is required and for how long a suitable reaction can be maintained have yet to be demonstrated. As

3.52.1 Oxidized Siliceous Tailing Revegetation (cont'd)

little as 60 t/ha was sufficient for grass, legume and conifer establishment on coarse tailings while 120 t/ha appears inadequate for vegetation to establish satisfactorily on the finer textured tailings. Mean pH for the 120 t/ha rate has decreased to 5.4 in 1983 from 6.3 the year before (Table 5.6). On the north half of the treatment pH has dropped to 4.5.

In 1984 an additional 90 t/ha CaCO_3 will be applied to the north half of each lime rate treatment increasing the range to 150, 180 and 210 t/ha. Vegetation will be re-established during the 1985 growing season. Monitoring will continue on all lime treatments in a continuing effort to determine if liming can be an efficient and practical technique for revegetation of oxidized siliceous tailings.

2. Covering Oxidized Siliceous Tailings with Overburden

Growth room and field studies have demonstrated that large amounts of lime possibly exceeding 200 t/ha-15 cm CaCO_3 may be required to sustain vegetation on oxidized siliceous tailings. Covering tailings with soil is an alternative approach for revegetating the phytotoxic mill waste. The feasibility of covering tailings with soil will depend, in large part, upon the depth of soil required to sustain a plant community. Factors considered to influence soil cover depth include water storage capacity of the soil, upward migration of acid salts from the underlying tailings and soil buffering capacity.

In October 1977 a pilot scale demonstration was initiated to determine the minimum depth of soil required to effectively bury oxidized siliceous tailings and sustain a self-supporting plant community of grass, forb, shrub and tree species. Approximately 1 ha of tailings was covered with soil ranging in depth from 15 cm to over 120 cm. Soil used was surficial material conserved during construction of the siliceous tailings pond extension. On May 4th, 1978 a grass-legume mixture composed of alfalfa (20%), birdsfoot trefoil (20%) crested wheatgrass (20%), tall wheatgrass (20%), Canada bluegrass (5%), hard fescue (5%), creeping

3.52.1 Oxidized Siliceous Tailing Revegetation (cont'd)

red fescue (5%) and tall fescue (5%) was broadcast on the soil surface at 84 kg/ha using an Erocon applicator. Prior to seeding, fertilizer supplying the equivalent of 50 kg/ha N, 250 kg/ha P_2O_5 and 100 kg/ha K_2O was also applied. In May 1979, 112 kg/ha K_2O was applied to sustain plant growth. During the same month seedlings of woody species including Douglas fir, ponderosa pine, western larch, black cottonwood, kinnickinnick and birch were planted on soil of varying depth. In late April 1980 and 1981 the equivalent of 52 kg/ha N, 64 kg/ha P_2O_5 and 40 kg/ha K_2O was applied as maintenance. Due to 100% mortality of woody species planted in 1979, woody species were replanted including Douglas fir, ponderosa pine, western larch, trembling aspen, black cottonwood and kinnickinick. Trees and shrubs were planted on sites with soil depths ranging from 15-30 cm, 30-60 cm, 60-120 cm and 120 cm plus. Prior to planting, herbaceous vegetation was removed from the planting sites by rototilling.

After six growing seasons crested wheatgrass - alfalfa vegetation continues to sustain satisfactory growth on soil covering tailings. Vegetative cover and specie composition vary with soil depth. With 30 cm or less soil, there was generally less than 50% vegetative cover dominated by crested wheatgrass with significant to minor amounts of alfalfa. A number of bare areas developed where soil cover was less than 15 cm. The number and size of such areas appear to be increasing. Vegetative growth was fair with both crested wheatgrass and alfalfa moderately chlorotic. With 30 to 60 cm soil cover, vegetative cover ranges between 50 and 75% varying with alfalfa population. The increase in vegetative cover over the shallower soil depth was due to increased alfalfa population and larger crested wheatgrass plants. Specie composition varied with distribution of alfalfa from areas with crested wheatgrass dominant and alfalfa significant to areas with both species co-dominant. With more than 60 cm soil cover vegetative cover increased to over 75% with alfalfa dominant and crested wheatgrass significant. Size, vigour and colour of alfalfa and crested wheatgrass plants improved as soil depth increased. Several western larch, aspen and

3.52.1 Oxidized Siliceous Tailing Revegetation (cont'd)

ponderosa pine were sustaining satisfactory growth on the shallow soil depth.

In 1980 soil was sampled at several depths above the tailing contact to monitor extent and degree of soil contamination. At 4 sites within the 30 cm and 60 cm soil depth ranges, soil samples were taken from the 30-15 cm, 15-7.5 cm and 7.5-0 cm. depth intervals above the tailings - soil interface to monitor soil pH and ECe. Soil sampled from the 7.5 cm zone above the tailings contact was more saline and acid in the reaction than soil sampled near the surface. The change in soil reaction and salinity was of greater magnitude and extended upward a greater distance above the tailings contact on sites covered by 30 cm of soil than on sites covered with 60 cm of soil. Almost 50% of the volume of soil over tailings covered by the 30 cm depth was very strongly acid and slightly saline. With 60 cm soil depth, contamination was limited to an insignificant degree. It should be noted that the tailing site was dry with the watertable well below the surface.

3.52.2 Recently Deposited Siliceous Tailing Revegetation

In June 1977 a field study (Project SC-8-77) was initiated on a recently abandoned section of the siliceous tailing disposal area with the objective of determining the lime requirement for maintaining actively oxidizing tailing within a reaction range suitable for grass-legume establishment and growth. Hydrated lime (90% by CaCO_3 equivalence) and dolomitic limestone (10%) were thoroughly mixed with the surface 15 cm of tailings at rates equivalent to 103, 206, 308 and 411 mt CaCO_3 per ha-15 cm. Lime strips were 1.5 m x 30 m in area and randomly arranged within five blocks situated around the perimeter of the tailing disposal area.

In mid-October 1977, ammonium phosphate and muriate of potash were incorporated with the limed tailings to supply the equivalent of 100 kg/ha N, 500 kg/ha P_2O_5 and 100 kg/ha K_2O before seeding to a mixture of acid and salt tolerant grasses and legumes. In May 1978, a maintenance fertilizer application of 46 kg/ha N, 56 kg/ha P_2O_5 and 35 kg/ha K_2O was broadcast on the tailings surface.

3.52.2 Recently Deposited Siliceous Tailing Revegetation (cont'd)

Seedling establishment during the 1978 growing season was poor. While many grasses germinated, seedlings failed to establish due to excessive concentrations of salts and possibly the highly alkaline reaction resulting from the very high rates of hydrated lime.

In September 1978, a 7.5 cm layer of commercial peat moss was spread on the surface of randomly selected subplots within each lime rate and incorporated to 15 cm, depth by rototiller. The entire experimental area was then reseeded to the following seed mixture: tall wheatgrass v. Orbit (30%), native mammoth wildrye (30%), creeping red fescue v. Boreal (20%) and alkali-grass v. lemmons (20%). The seed mixture was broadcast at 100 kg/ha on October 26th, 1978. The seed was incorporated by light raking. In late April 1979, a maintenance fertilizer application of 40 kg/ha N and 200 kg/ha P_2O_5 was broadcast on the tailings surface.

Seedling establishment was evaluated in late June 1979 immediately prior to destruction of the experiment due to tailing dyke construction. Limed tailing were also sampled for pH and electrical conductivity analysis.

Once again grass seedlings failed to establish on limed siliceous tailings. Numerous seedlings emerged with populations ranging from poor to satisfactory. Seedling mortality however was extremely high with generally less than 5% of the treated areas having any plant cover. The emerging seedlings were severely chlorotic and dessicated. Leaves were bleached to a white colour, curled inwards and curved in the form of a sickle. Many leaves were shredded by the "sand-blasting" effect of wind blown tailings.

Early growing season weather conditions were warmer and drier than normal. Warm, drying winds blowing across the hot tailings surface contributed to high seedling mortality. Of the few surviving seedlings, those growing on peat-treated tailings were the more vigorous in appearance.

Siliceous tailings reaction two years after lime application varied widely. Natural variation in tailings lime requirement, lime rate and peat moss all appeared to influence current years tailings pH. The low lime rate of 100 mt $CaCO_3$ /ha-15 cm was not sufficient to maintain a reaction range suitable for

3.52.2 Recently Deposited Siliceous Tailing Revegetation (cont'd)

plant growth over the entire experimental area. Sections of tailings limed at the low rate were extremely acid with pH as low as 2.4 while other sections limed at the same rate were moderately alkaline with pH as high as 7.8. Application of 200 mt/ha maintained a mildly to moderately alkaline reaction with pH ranging from 7.6 to 7.8. Application of higher rates of lime resulted in tailing even more alkaline which, for a period of years following application, may be too alkaline for seedling establishment. Incorporation of the 7.5 cm of peat moss reduced tailing pH by 0.5 to 1.5 units. Similarly, tailings pH continued to decrease with time being 0.5 to 0.3 pH units lower in 1979 than 1978.

Lime rate and peat moss influenced tailings soluble salt concentrations. Tailings ECe was highest for tailings limed at the lowest and highest rates. On tailings limed at the low rate, high ECe values were coincident with the lowest pH values and, conversely, with tailings limed at the high rate, high ECe values were coincident with the highest pH values.

Incorporation of peat moss reduced tailings ECe having the greatest benefit on tailings with the highest salt concentrations. ECe changed only slightly between 1978 and 1979, increasing slightly at the low lime rate and decreasing slightly at the high lime rate.

Tailings reaction and salinity levels most suitable for revegetation resulted from incorporation of 200 t/ha CaCO_3 and 7.5 cm of peat moss. pH and ECe averaged 6.8 and 2.6 mmhos/cm, both acceptable for growth of many plant species. Addition of peat moss increased tailings saturation percentage from 40% to 112%, clearly indicating that tailings moisture storage capacity can be increased by addition of organic matter.

The failure of seedlings to establish on siliceous tailings mixed with peat moss and limed at 200 t CaCO_3 /ha may be attributed to causes other than tailing reaction, salinity or available moisture. Drier than normal weather accompanied by hot, drying winds provided a harsh environment for establishment of seedlings following emergence. In addition to desiccation many seedlings were severely damaged by wind blown tailings.

3.52.3 Oxidized Iron Tailing Revegetation

1. Liming

A small scale field study similar to that described for oxidized siliceous tailing in section 3.52.1 (Project SC-3-78) was established on oxidized iron tailing in June 1978. Agricultural hydrated lime was applied at the equivalent of 90, 180, 270 and 360 t CaCO_3 /ha-15 cm and incorporated using a rototiller. Limed iron tailings were seeded, fertilized, maintained and monitored in the same manner as described for siliceous tailings. Trends observed since plot establishment are discussed.

The 90 t/ha lime rate was not sufficient to maintain pH above 2 through the first growing season (Table 5.8). On iron tailing limed with 180 t/ha and higher seedling establishment was poor in 1979 due to very dry and warm weather resulting in sparse plant populations and less than satisfactory vegetative cover in 1980 (Table 5.7). Additional grass and birdsfoot trefoil seedlings emerged during 1980 but survival was poor resulting in continued low plant populations and vegetative cover during 1981. Maximum cover and biomass were produced on tailings limed with 180 t/ha and averaged 18% and 730 kg/ha respectively.

Survival and growth of mammoth wildrye was satisfactory on tailings limed with 180 t/ha CaCO_3 and higher (Table 5.9).

In 1981 grass vegetation contained elevated concentrations of Pb and Zn relative to concentrations in grass growing on normal uncontaminated soil. Metal concentrations were highest in vegetation growing on tailings limed at 180 t/ha averaging 83 ppm Pb and 51 ppm Zn.

Tailing pH continued to decrease over time (Table 5.8). By 1981, tailings limed with 180 t CaCO_3 /ha had pH of 4.5. By 1983, all limed tailings were very strongly acid with pH between 2.4 and 3.4.

By 1983 vegetation had completely died out on the 90 t CaCO_3 /ha treatment while plant population and vegetative cover decreased on the 180 t/ha treatment. Maximum vegetative cover currently sus-

3.52.3 Oxidized Iron Tailing Revegetation (cont'd)

tained on tailing limed at 270 t/ha. Grass species surviving include Canada bluegrass with significant creeping red fescue, mammoth wildrye, red top and minor crested wheatgrass. Grass plants appeared vigorous with only minor chlorosis. There were no surviving conifers in 1983.

2. Covering Oxidized Iron Tailings with Overburden

Growth room and field studies have demonstrated that extremely large amounts of liming materials, probably in excess of 400 t CaCO_3 /ha-15 cm, would be required to maintain oxidized iron tailing within a reaction range tolerated by grasses and legumes. To be effective liming materials must be thoroughly incorporated with the surface 15 to 30 cm of tailing. With oxidation, iron tailing developed a hard impermeable layer up to 7.5 cm thick. This hard layer is generally found at or within 30 cm of the surface. Effective incorporation of liming materials is essentially prevented by this adverse physical condition.

Covering oxidized iron tailing with overburden is an alternative approach for revegetating this phytotoxic mill waste. As was discussed in section 3.52.1, the feasibility of covering oxidized iron tailing with overburden will depend upon the depth of overburden required to sustain a plant community. However, unlike the siliceous tailing deposit, a significant portion of the iron tailing deposit is saturated to within a meter of the surface. Ames (8) demonstrated in a column study that, under semi-arid conditions as exist at Kimberley, overburden placed in direct contact with oxidized iron tailings having a shallow water table, can become contaminated by acids, salts and metals migrating upwards from the tailing mass by capillary movement. Salts of Ca, Fe, Zn and Cu rapidly migrated into the overburden. In addition, Al and Mn were released from soil minerals altered as result of the development of extreme acid conditions within the overburden material. However, it was also demonstrated that a gravel layer placed between the tailing and overburden was an effective means of interrupting capillary flow of tailing fluids and preventing contamination of overburden.

3.52.3 Oxidized Iron Tailing Revegetation (cont'd)

The use of coarse textured material as a contamination barrier has subsequently been proven effective under field conditions. In October 1978, a small scale field study was initiated to determine what thickness of overburden was required to bury iron tailings and sustain a self-supporting plant community of grass, legume, shrub and tree species. The experiment was located on a site where tailings are saturated to the surface at least for part of the growing season. An important aspect of the study was to access the effectiveness of a layer of float rock placed between the tailing and overburden to provide safe access for equipment spreading overburden and to function as a barrier preventing migration of acid salts from the iron tailings upward into the overburden. Glacial till was placed at thicknesses of 30, 60 and 120 cm directly on the tailings surface and on a 30 to 45 cm thick layer of float rock which had been placed on tailings. A grass-legume mixture composed of crested wheatgrass (20%), tall wheatgrass (20%), birdsfoot trefoil (20%), Rambler alfalfa (20%), hard fescue (5%), creeping red fescue (5%), tall fescue (5%) and Canada bluegrass (5%) was broadcast on the overburden in late April 1979. Prior to seeding, fertilizer supplying the equivalent of 50 kg/ha N, 250 kg/ha P_2O_5 and 100 kg/ha K_2O was also applied. Maintenance fertilizer supplying 52 kg/ha N, 64 kg/ha P_2O_5 and 40 kg/ha K_2O was applied in the spring of 1981 and 1982.

Evidence of overburden contamination was observed during 1980, the second growing season, when the 30 cm layer of overburden in direct contact with iron tailings developed dark staining, a lower pH (3.2) and a higher E_{Ce} (6.4 mmhos/cm) relative to overburden in contact with float rock i.e., pH 5.1 and E_{Ce} 0.9 mmhos/cm. Vegetative cover and biomass were not adversely affected; however, grass and alfalfa roots did not penetrate the 10 cm of overburden above the tailing contact. Roots grew normally to that depth and then extended horizontally rather than vertically. It is of interest to note that vegetative cover and biomass were actually higher in 1980 on 30 and 60 cm of overburden placed in direct contact with iron tailings. Reduced vegetative growth with the float rock barrier has subsequently been

3.52.3 Oxidized Iron Tailing Revegetation (cont'd)

attributed to less available moisture caused by float cutting off upward migration of moisture from tailings.

By 1983, the fifth growing season, vegetation on 30 cm of overburden in direct contact with tailing had completely died out while vegetation cover on the 60 cm layer had decreased relative to that of 60 cm of overburden on float. Also pH of overburden within the 60 cm layer for 30 cm above the contact with tailings decreased to 2.6 compared to 4.2 for overburden on the float barrier. The drop in pH was also accompanied by an increase in ECe to 7.3 mmhos/cm compared to 2.6 with the float barrier.

In addition to demonstrating the effectiveness of float rock at preventing overburden contamination, the study has demonstrated that drought tolerant crested wheatgrass can sustain growth on as little as 30 cm of overburden placed on float.

Increasing overburden depth to 60 cm improved crested wheatgrass vegetative growth and cover while sustaining a significant population of alfalfa. Increasing overburden depth to 120 cm did not increase alfalfa or crested wheatgrass growth and cover relative to the 60 cm depth. Within the 60 cm depth, overburden was powder dry from 15 cm below the surface to the contact with float rock when sampled in late June 1983. Grass and alfalfa roots extended from near the surface to the contact with float rock. These observations suggest that growth and survival of plants other than the most drought tolerant may be limited when less than 60 cm of overburden is placed on a float rock barrier.

The overburden-float rock study was expanded to 0.25 ha during the fall of 1980 (Project SC-3-80). Float rock was spread in a layer 30 to 45 cm thick on an iron tailing site where the watertable periodically rises to the tailings surface. Up to 45 cm of float was required over much of this site to stabilize the surface for spreading overburden. Glacial till was excavated from a nearby site and spread over the float rock at varying depths ranging up to 60 cm.

3.52.3 Oxidized Iron Tailing Revegetation (cont'd)

Two legume-grass mixtures were seeded on the area on April 21, 1981. The mixtures were as follows: sainfoin (50%), fairway crested wheatgrass (25%) and russian wildrye grass (25%) seeded at 100 kg/ha and rambler alfalfa (40%), nordan crested wheatgrass (40%) and hard fescue (20%) seeded at 50 kg/ha. Seed was broadcast on the soil surface. The equivalent of 55 kg/ha N, 275 kg/ha P_2O_5 and 102 kg/ha K_2O was also broadcast prior to seeding. In addition 50 seedlings each of ponderosa pine, Douglas fir, alder, willow, western poplar, kinnickinnick and hybrid poplar were planted along unseeded strips traversing the length of the demonstration area. In 1982, maintenance fertilizer was applied on April 19, supplying the equivalent of 52 kg/ha N, 64 kg/ha P_2O_5 and 40 kg/ha K_2O . On May 11, an additional 60 seedlings each of lodgepole pine, Engelmann spruce and Douglas fir were planted along the unseeded strips originally planted with woody species in 1981. In 1983, 40 kg/ha N was applied as maintenance to seed mix 1 only i.e., sainfoin, crested wheatgrass and russian wildrye. Vegetative cover, species cover and biomass were monitored in late June 1982 and 1983. Results are presented in Table 5.10.

In general a satisfactory vegetative cover sustained growth on overburden seeded with both seed mixtures through 1983. Vegetative cover, species cover and biomass varied with seed mix and probably depth of overburden.

With seed mix 1, vegetation was characterized by dense populations of crested wheatgrass. Plants were small with dessicated leaf tips and seed heads. The area seeded to mix 1 has a shallower cover of overburden generally less than 30 cm thick. Sainfoin and russian wildrye grass did not establish.

Vegetation growing on overburden seeded to mix 2 was more variable. Overburden depth was greater ranging from 30 to 60 cm. Areas with the greater depth of overburden sustained a dense vegetation cover of crested wheatgrass with significant alfalfa. With decreasing overburden thickness vegetative cover and biomass decreased due to smaller crested wheatgrass plants and a decrease in alfalfa population and growth. Hard fescue cover increased on the shallower overburden.

3.52.3 Oxidized Iron Tailing Revegetation (cont'd)

Alfalfa cover decreased in 1983 to only half of 1982 cover. Growth and development of all species was limited by moisture stress. Overburden was powder dry from surface to contact with the float rock barrier.

Tree and shrub seedlings suffered 100% mortality probably due to severe moisture stress. Tree planting strips have developed a moderately dense grass cover dominated by Canada bluegrass with significant crested wheatgrass, red top and hard fescue.

3.52.4 Gypsum Revegetation

Gypsum, a waste product of phosphoric acid production, is disposed of in a pond immediately south of the iron tailing pond and will eventually butt against the iron tailing dyke. Gypsum is also extremely acid in reaction, however, relative to siliceous and iron tailings has a low lime requirement.

Growth room and field studies have been in progress since 1975 to assess suitability of gypsum as a growth medium for plants and determine the potential for using gypsum as a material for covering iron and, possibly, siliceous tailings. In summary birdsfoot trefoil, creeping red fescue, hard fescue, crested wheatgrass, western wheatgrass and woody species trembling aspen, willow, silver maple, white spruce and poplar have sustained growth for up to eight growing seasons on gypsum limed with 8, 16 and 24 t CaCO_3 as hydrated lime and 14 and 22 t CaCO_3 as dolomitic limestone. On gypsum treated with adequate lime, satisfactory grass growth has been sustained by annual application of 50 kg/ha N. Discontinuing maintenance N resulted in severe deterioration in grass growth and cover. Discontinuing maintenance fertilizer did not adversely affect vegetative cover of vegetation dominated by the N-fixing legume birdsfoot trefoil. Dense stands of birdsfoot trefoil with significant amounts of crested wheatgrass have sustained satisfactory growth for five growing seasons without maintenance. Birdsfoot trefoil has been a prolific seed producer and has spread throughout areas originally seeded with other species.

Vegetation growing on gypsum tend to accumulate fluorine often in concentrations exceeding suggested safe levels for cattle and horses i.e., greater than

3.52.4 Gypsum Revegetation (cont'd)

50 and 60 ppm F, respectively. Fluorine in vegetation sampled near the end of the 1982 growing season varied widely both within and among plant species and was influenced to a lesser degree by source of lime. Hard fescue growing on gypsum limed with hydrated lime averaged 59 ppm F, similar to or lower than concentrations in native grasses growing on natural soils adjacent the gypsum experimental area. Native grasses needlegrass, idaho fescue, pinegrass and western wheatgrass concentrations averaged 12, 55, 88 and 247 ppm F, respectively. Wheatgrasses growing on gypsum limed with hydrated lime averaged as follows: crested wheatgrass 127 ppm F; tall wheatgrass 126 ppm F, western wheatgrass 148 ppm F.

Fluorine concentrations in birdsfoot trefoil were higher than those of the grasses. Trefoil plants growing on gypsum limed to pH 6 with a mixture of dolomitic limestone and hydrated lime contained 210 ppm F. On gypsum limed to pH 4.9 birdsfoot trefoil accumulated 485 ppm F.

Several woody species growing on gypsum accumulated extremely high concentrations of fluorine. Trembling aspen, willow and poplar leaves from trees growing on gypsum limed to pH 6 contained 757, 593 and 415 ppm F, respectively. The same species growing on natural soils contained 85, 18 and 15 ppm F, respectively.

4. OPERATIONAL REVEGETATION

Due to the extreme phytotoxic nature of siliceous and iron tailings, progress towards development of effective and practical revegetation techniques has been slow. In addition the Sullivan is an operating mine with tailing disposal areas in active use. Implementation of operational scale revegetation must, therefore, be deferred until revegetation techniques have been proven effective and the tailing disposal areas have been abandoned.

Actual costs to successfully revegetate iron and siliceous tailings are, therefore, not available. Cost estimates for covering siliceous and iron tailings with a less toxic growth medium range from \$34,000 to \$48,000 per hectare. Nature and volume of growth medium, location of source, mode of transport and placement are significant cost factors which remain to be resolved.

5. FUTURE INVESTIGATIONS

5.1 Siliceous Tailing

At abandonment the siliceous tailing deposit will be covered with recent deposits of actively oxidizing tailing. Limited experience suggests that actively oxidizing tailing may be more difficult to revegetate than tailings which have oxidized and weathered for many years. Long term field investigations are required to assess the potential of liming and covering with overburden as revegetation techniques for actively oxidizing siliceous tailing. Covering fresh deposits of tailing with a layer of overburden may limit the rate and extent of tailing oxidation reducing potential for contaminating surface and ground waters as well as providing a suitable growth medium for plants.

Current liming studies on oxidized siliceous tailing should be expanded to include a wider range of lime application rates and additional sites to determine lime requirement for long term self-sustained vegetation. Lime requirement determined in the field should be compared with lime requirement determined in the laboratory using the BaCl_2 -TEA technique.

5.2 Iron Tailing

When abandoned the iron tailing deposit will have large areas of oxidized as well as recently deposited tailings on the surface. An extremely high lime requirement, salinity and adverse physical properties essentially preclude liming as an effective revegetation technique for oxidized iron tailing. It is logical to assume that actively oxidizing iron tailing will consume large quantities of lime, accumulate salts and develop a hard impervious layer which will impede lime incorporation.

Therefore covering iron tailing with a more suitable growth medium appears to be the only effective technique for revegetating the iron tailing deposit. Future investigations will be directed toward developing the most practical method of covering iron tailing with a growth medium capable of sustaining vegetation which meets revegetation objectives. Alternative growth media include overburden, gypsum and siliceous tailings; however, some problems are encountered with each type of material. Gypsum and siliceous tailing are available in ample quantity but overburden reserves within a practical hauling distance of the iron pond are unknown. Vegetation can sustain growth on gypsum, but may accumulate fluorine in concentrations potentially hazardous to grazing animals while a technique for establishing and sustaining vegetation on recent deposits of siliceous tailing has yet to be demonstrated. Investigations must address these problems until sufficient information is available to develop an effective and practical revegetation plan.

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TABLE 2-1

LONG TERM CLIMATIC RECORDS FROM COMINCO LTD. FERTILIZER OPERATIONS

AT KIMBERLEY, B.C., FORTY YEAR MEANS AND EXTREMES

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	ANNUAL
TEMPERATURE °C													
Mean Daily	-9.0	-5.7	-0.4	6.2	10.9	14.5	18.2	17.0	12.5	5.9	-2.0	-5.9	5.0
Maximum	10	14	20	28	31	34.5	37	36	35	28	18	15	37
Minimum	-40	-35	-35	-12	-12	-2	-2	-1	-6	-13	-32	-35	-40
PRECIPITATION													
Rain (mm)	6.0	5.1	5.8	18.4	51.1	46.8	21.4	36.2	25.4	24.0	12.8	8.6	238
Snow (cm)	45.0	29.1	17.2	5.1	0.7	0.0	0.0	0.0	0.5	5.8	26.4	41.6	171
Total (mm)	51.0	34.2	23.0	23.5	51.8	46.8	21.4	36.4	25.9	29.9	39.2	50.2	409
Maximum ppt. in 24 hours (mm)	52.5	25.6	17.8	22.4	56.5	29.2	28.4	35.5	26.7	27.0	38.1	40.0	40.0

TABLE 2.2

DIRECTION AND VELOCITY OF WIND AT COMINCO LTD.FERTILIZER OPERATIONS, KIMBERLEY, B.C.10 YEAR MEAN (1971 - 1980)

	<u>DIRECTION FREQUENCY (%)</u>	<u>MEAN VELOCITY (kph)</u>
N	10.6	4.3
NE	7.9	4.2
E	6.7	4.3
SE	12.6	4.1
S	3.5	4.5
SW	8.7	5.7
W	20.2	8.9
NW	13.0	5.7
CALM	16.8	

MONTHLY PRECIPITATION RECORDED AT SULLIVAN MINE AND CONCENTRATOR

TABLE 2.3

MONTH	1972		1973		1974		1975		1976		1977		1978		1979		1980		1981		1982	
	MEAN	MINE	MEAN	MINE	MEAN	MINE	MEAN	MINE	MEAN	MINE	MEAN	MINE	MEAN	MINE	MEAN	MINE	MEAN	MINE	MEAN	MINE	MEAN	MINE
	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)
January	79	45	125	86	56	49	51	62	37	50	7	26	63	74	10	31	53	70	35	50	57	81
February	57	31	96	64	32	35	65	70	71	64	10	12	24	32	63	54	50	35	48	47	83	77
March	43	21	63	27	40	24	49	21	32	33	31	43	12	8	16	25	31	33	7	4	44	56
April	38	19	63	45	15	13	24	22	28	64	-	4	71	68	30	29	17	24	21	13	27	15
May	49	32	21	15	19	9	9	11	41	22	65	45	82	60	16	20	52	46	75	94	21	32
June	64	50	82	83	41	46	24	22	49	43	50	33	35	33	2	8	48	47	54	82	11	43
July	29	19	61	60	3	3	50	54	47	19	34	37	54	39	5	11	13	22	45	69	20	18
August	37	35	35	36	42	32	98	64	82	80	41	27	21	29	21	30	18	46	13	7	18	25
September	38	23	74	54	17	16	34	33	8	11	53	52	48	19	2	1	12	24	6	13	85	69
October	51	31	51	32	56	23	90	129	13	18	11	11	16	9	33	21	20	25	27	20	9	13
November	64	35	15	12	122	117	45	37	37	26	73	69	42	26	6	29	46	70	39	47	48	46
December	78	42	126	69	94	61	96	67	17	29	72	90	19	51	115	80	138	130	70	67	72	62
30Yr. Annual	627	381	817	583	538	428	633	592	461	458	426	431	489	448	319	340	477	571	438	513	493	537
30Yr. Seasonal	217	159	273	248	122	106	215	184	227	175	223	194	240	180	46	70	143	185	195	285	155	187

TABLE 2-4

MEAN MONTHLY TEMPERATURE RECORDED AT SULLIVAN MINE AND CONCENTRATOR

MONTH	50 YEAR MEAN		1972		1973		1975		1976		1977		1978		1979		1980		1981		1982	
	MINE	MILL	MINE	MILL	MINE	MILL	MINE	MILL	MINE	MILL	MINE	MILL	MINE	MILL	MINE	MILL	MINE	MILL	MINE	MILL	MINE	MILL
January	-9	-11	-11	-8	-9	-8	-9	-8	-9	-9	-9	-9	-6	-8	-15	-17	-	-12	-	-4	-10	
February	-7	-5	-4	-3	-6	-3	-10	-8	-3	-3	0	-4	-4	-3	-4	-4	-	-2	-	-2	-7	
March	-1	3	1	3	-0.6	3	-5	-2	-2	1	1	2	3	3	1	3	-	0.5	5	5	-0.6	
April	6	4	2	4	3	6	1	4	7	9	9	6	6	7	6	6	8	10	7	7	3	
May	11	12	11	12	10	12	8	11	12	11	11	11	9	10	11	12	13	15	12	9	9	
June	14	15	13	15	13	15	14	15	13	18	18	16	17	17	17	18	15	16	13	13	16	
July	18	17	17	21	17	21	19	22	18	18	18	19	20	20	21	22	20	20	17	17	-	
August	16	20	15	19	12	15	12	15	16	16	16	16	17	17	21	22	14	16	22	16	16	
September	12	8	10	11	14	12	14	14	16	11	7	7	8	8	16	17	13	14	15	11	11	
October	6	3	4	6	3	5	3	5	7	7	7	7	7	6	4	9	8	9	4	5	4	
November	-2	-0.3	-2	-7	-7	-4	-4	-3	-2	-3	-3	-3	-3	-4	-3	-3	-	0.9	-0.7	-5	-5	
December	-6	-10	-9	-7	-7	-4	-8	-4	-3	-3	-10	-9	-9	-9	-1	-1.4	-	-3	-9	-9	-9	
Annual	5	4	5	6	3	5	3	5	6	6	6	6	5	6	6	7	-	7	7	7	-	
Seasonal	14	15	15	16	13	15	15	15	15	15	15	15	14	15	17	18	15	16	16	16	-	

TABLE 2.5

GROWING SEASON CLIMATIC DATA FOR
KIMBERLEY AND CRANBROOK AIRPORTS

	<u>CRANBROOK</u>	<u>KIMBERLEY</u>
Latitude (N)	49°36'	48°44'
Longitude (W)	115°47'	115°47'
Elevation (m)	930	915
Growing Degree Days Above 5°C	1550	1530
Freeze Free Period (days)	91	92
Seasonal (May - Sept) Precipitation (mm)	179	163
Seasonal Potential Evapotranspiration (mm)	532	540
Climatic Moisture Deficit (mm)	-353	-377

Source: Climatic Capability Classification For Agriculture in British Columbia. APD Technical Paper 4, 1981. Prepared by Climatology Unit, Air Studies Branch, Ministry of Environment, Victoria.

TABLE 3.1

TOTAL ELEMENTAL ANALYSIS OF SULLIVAN TAILINGS

	Siliceous ²	<u>Si - Fe³</u>		<u>Si-Fe⁴</u>
	<u>Fresh</u>	<u>Mean</u>	<u>Range</u>	
Calcium	0.08	0.32	0.11 - 0.44	0.16
Magnesium	1.07	1.40	1.12 - 1.50	1.20
Sodium	0.27	0.95	0.67 - 1.15	0.49
Potassium	0.38	0.92	0.74 - 1.03	0.65
Iron	45.4	15.9	12.3 - 19.8	25.9
Manganese	0.17	0.44	0.25 - 0.72	0.49
Aluminum	2.3	5.2	4.2 - 5.8	4.7
Silica	2	10	8 - 12	7
Cadmium	0.001	0.001	.001 - .002	0.011
Cobalt	<0.01	<0.01	<0.01	<0.01
Chromium	0.001	0.005	.004 - .006	0.007
Copper	0.05	0.06	0.02 - 0.11	0.07
Molybdenum	<0.01	<0.01	<0.01	<0.01
Nickel	0.02	0.03	0.02 - 0.03	0.03
Lead	0.59	0.35	0.25 - 0.48	0.44
Titanium	0.2	0.3	0.2 - 0.3	0.1
Zinc	0.48	0.13	0.10 - 0.14	0.54
pH	4.3	2.5	2.2 - 2.5	4.0

1. Analyses conducted at Department Soil Science, U.B.C. using the method outlined by Buckley, D.E. and R.C. Crauston, 1971. Atomic absorption analysis of 18 elements from a single decomposition of alumino-silicate. Chem. Geol. 7: 273-284.
2. Analyses of one sample identified as freshly deposited siliceous tailings. Iron content suggests material probably iron tailings.
3. Analysis of four samples from different depth intervals between surface and 70 cm within a single profile.
4. Analysis of one sample from below 70 cm depth from same profile as 3.

TABLE 3-2

CERTAIN CHEMICAL PROPERTIES OF SULLIVAN TAILINGS

	pH		N	O-M	S	CEC	Ca ⁺⁺	Exchangeable Cations			n
	H ₂ O	0.1M CaCl ₂						Mg ⁺⁺	Na ⁺	K ⁺	
			(%)	(%)	(%)	(me/100g)					
1. UBC Department Soil Science											
Iron, fresh:	4.3	4.0	<0.006	<0.1	7.4	2.8	18	2.0	0.05	0.14	1
Siliceous-high Fe: Oxidized											
X̄:	2.5	2.6	0.012	0.24	1.2	6.9	59	5.4	0.01	0.03	12
Range:	2.2-3.1	2.3-3.2	<0.006-0.024	<0.1-0.5	0.38-1.98	3.7-8.9	11-77	1.3-12	<0.01-0.02	<0.01-0.09	
Siliceous-high Fe:											
X̄:	4.0	4.0	<0.006	<0.1	6.4	9.2	56	1.7	0.01	0.05	1
Iron: Oxidized:											
X̄:	2.2	2.3	0.013	0.26	2.7	10.2	77	2.0	0.01	0.03	4
Range:	2.0-2.3	2.1-2.4	<0.006-0.028	<0.1-0.6	0.6-5.3	8.8-11.9	1-125	0.4-5.9	<0.01-0.01	<0.01-0.04	
2. ComInco Ltd											
Siliceous: Unoxidized											
X̄:	6.2	-	0.017	0.34	-	1.7	22	1.4	0.1	0.2	3(14)
Range:	5.6-6.9	-	.003-.024	<0.1-0.5	-	1.3-2.3	19-25	0.7-2.2	<0.01-0.1	0.2-0.3	
Siliceous: Oxidized											
X̄:	2.6	-	0.003	0.06	-	5.9	44	4.0	<0.01	0.2	1(3)
Range:	2.4-2.8	-									
Iron: Unoxidized											
X̄:	6.0	-	0.010	0.20	-	1.1	7	1.4	0.1	0.2	1(2)
Range:	5.8-6.1	-	.006-.013	0.1-0.26	-	-	-	-	-	-	
Iron: Oxidized											
X̄:	2.2	-	0.023	0.46	-	5.1	5	1.5	0.1	0.3	4(11)
Range:	2.0-2.5	-	.003-.061	<0.1-1.2	-	3.8-6.2	0.3-11	0.3-2.3	<0.01-0.1	0.2-0.4	

1. Organic matter = %N x 20

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TABLE 3.3

AVAILABLE NUTRIENTS IN SULLIVAN TAILINGS

	NO ₃ -N	P	K	Ca	Mg	Cu	Fe	Mn	Al	Zn	Pb
						(ppm)					
1. UBC Department Soil Science											
Iron fresh:n=1	-	<0.1	65	3350	264	104	15000	238	-	355	-
$\bar{x}$:											
Siliceous-high Fe: Oxidized:n=12											
$\bar{x}$:	-	2.1	3	6875	644	52	3566	145	-	173	-
Range:	-	0.9-9.4	4.3-6.3	2750-9375	149-1048	4-392	864-9999	43-230	-	5-454	-
Siliceous-high Fe:n=1											
$\bar{x}$:	-	2.6	45	7875	211	149	4249	49	-	625	-
Iron: Oxidized:n=4											
$\bar{x}$:	-	1.2	2	5094	233	6	3554	16	-	103	-
Range:	-	1.0-1.3	<1.3-3.8	500-8250	35-680	4-9	2069-5599	3-40	-	42-230	-
2. Cominco Ltd:											
Siliceous: Unoxidized:n=14(3)											
$\bar{x}$:	<1	2	49	2632	119	4	918	35	1	663	1819
Range:	<1	1-3	<25-66	~~1273-5000~~ 1273-5000	33-268	<1-9	230-1350	18-55	<2-2	240-900	875-3300
Siliceous: Oxidized:n=3(1)											
$\bar{x}$:	<1	2	<25	>5000	>500	1	2750	55	-	95	15
Range:	<1	2-3	<25	>5000	>500	-	-	-	-	-	-
Iron: Unoxidized:n=2(1)											
$\bar{x}$:	<1	<2	31	835	83	2	2050	42	<2	625	4400
Range:	<1	<2	<25-43	620-1050	38-177	-	-	-	-	-	-
Iron: Oxidized:n=11(4)											
$\bar{x}$:	1	7	<25	368	75	1	9363	154	90	111	68
Range:	<1-2	2-29	<25	<250-4000	<25->500	<1-1	1950-14,500	6-490	40-140	40-160	20-160

TABLE 3.4

CONCENTRATION AND COMPOSITION OF WATER SOLUBLE SALTS IN SULLIVAN TAILINGS

Soil Water ratio	ECa ² (mhos/cm) (gm/gm)	Water Soluble Cations and Anions ¹							SAR ³	n	
		Ca	Mg	Na	K	Cl ⁻	CO ₃	HCO ₃			SO ₄
(me/100gm)											
1. UBC Department Soil Science											
Iron, fresh:	17	0.59	1.93	0.01	0.03	-	<.002	0.004	11.5	-	1
Siliceous-high Fe: Oxidized											
$\bar{x}$:	13	0.21	3.25	<.01	<.01	-	<.003	<.001	10.9	-	4
Range:	9-22	0.03-0.4	1.51-6.60	<.01	<.01	-	<.003	<.001	4.1-16.7	-	
Siliceous-high Fe:											
$\bar{x}$:	19	0.02	1.63	<.01	<.01	-	<.003	0.005	15.9	-	1
2. Cominco Ltd											
Siliceous: Unoxidized											
$\bar{x}$:	4	23	8.39	1.22	0.94	15.3	-	-	>8.1	0.28	5
Range:	3-5	20-30	3.90-14.5	0.21-2.02	0.57-1.47	6-42	-	-	-	.07-.48	
Siliceous: Oxidized											
$\bar{x}$:	14	29	67	0.18	0.06	0.28	-	-	>12.6	0.02	1
Iron: Unoxidized											
$\bar{x}$:	4	19	4.6	0.92	0.73	18.2	-	-	-	0.23	2
Range:	3-4	18-20	2.1-7.3	0.73-1.1	0.52-0.92	7.8-29.4	-	-	-	-	
Iron: Oxidized											
$\bar{x}$:	14	22	13.3	0.86	0.05	0.54	-	-	>12.2	0.23	5
Range:	11-17	5-42	2.9-28	0.31-1.65	<.01-0.26	0.22-0.99	-	-	>12.2	0.10-0.38	

NOTE: 1. Cominco Ltd. sample concentrations of water soluble cations and anions originally expressed as me/l. Converted as follows to me/100gm

$$= \frac{\text{me/l} \times \text{satn} \times 1000}{1000}$$

2. SAR abbreviation for sodium adsorption ratio.

3. E_{oc} abbreviation for electrical conductivity.

TABLE 3-5

CERTAIN PHYSICAL PROPERTIES OF SULLIVAN TAILINGS

Clay	Particle Size		Texture	Particle Density (gm/cc)	Bulk Density (gm/cc)	Total Porosity (cm/cm)	Water Content (cm/cm)	Aeration at Field Capacity (cm/cm) (%)
	Silt	Sand (%)						
8.1	42.6	49.2	1	2.17	1.17	0.51	0.13	0.38 75
5.9-9.5	29.7-56.8	37.3-61.3	sl-sll	-	0.97-1.33	-	-	-
2.1	30.8	67.1	sl	3.34	1.86	0.44	0.17	0.25 57
Iron, fresh: n=1								
3.85								

1. UBC Department of Soil Science
 Siliceous-high Fe, Oxidized: n=3

x:
 Range:

Siliceous-high Fe: n=1

Iron, fresh: n=1

2. ComInco Ltd

Siliceous:

Unoxidized

Oxidized

Iron:

Unoxidized

Oxidized

TABLE 3.6

WATER RETENTION DATA FOR SULLIVAN TAILINGS

<u>TENSION:</u>		<u>0.1</u>	<u>0.9</u>	<u>3</u>	<u>15</u>	<u>AWSC</u>
		<u>bar</u>	<u>bar</u>	<u>bars</u>	<u>bars</u>	
				<u>(gm/gm)</u>		
1. UBC Department Soil Science	<u>Iron Fresh: n=1</u>	0.28	0.12	0.08	0.03	0.24
	<u>Siliceous-high Fe, Oxidized: n=4</u>	0.26	0.13	0.11	0.08	0.19
	<u>x:</u>	13-38	.06-.16	.05-.13	.05-.11	.09-.32
	<u>Range:</u>					
<u>Siliceous-high Fe: n=1</u>		0.28	0.12	0.08	0.03	0.24
2. Cominco Ltd	<u>Siliceous</u>					
	<u>Unoxidized</u>	.16	-	-	.02	.14
	<u>Oxidized</u>	.32	-	-	.13	.20
	<u>Iron</u>					
	<u>Unoxidized</u>	.12	-	-	.01	.11
	<u>Oxidized</u>	.29	-	-	.10	.19

TABLE 3.7

CHEMICAL AND PHYSICAL PROPERTIES OF SILICEOUS TAILINGS
IN OXIDIZED AND UNOXIDIZED STATES

<u>PROPERTY</u>		<u>SILICEOUS TAILINGS</u>	
		<u>UNOXIDIZED</u>	<u>OXIDIZED</u>
Colour		gray-black 10Y4/2	orange-brown 10YR5/6
Texture		silt loam	silt loam
Particle Size: sand	(%)	35	32
silt	(%)	55	53
clay	(%)	10	15
Moisture Retention:			
field capacity	(%)	16	32
permanent wilting	(%)	2	12
available water	(%)	14	20
pH		6.5	2.6
Exchange acidity	(meq/100g)	1.3	311
Active acidity	(t/1000t)	0.7	112
Residual acidity	(t/1000t)	328	115
Total S	(%)	10.5	3.7
CEC	(meq/100g)	1.7	5.9
Exchangeable Ca	(meq/100g)	22	44
Exchangeable Mg	(meq/100g)	1.4	4.0
ECe	(mmhos/cm)	3.6	14
Water soluble Ca	(meq/l)	648	515
Water soluble Mg	(meq/l)	233	1200
Water soluble Cl	(meq/l)	424	5
SAR		0.28	0.02
Saturation Percentage		36	56
Extractable Fe	(NH ₄ OAc)(ppm)	918	2750
Extractable Mn	(CaCl ₂)(ppm)	35	55
Extractable Al	(CaCl ₂)(ppm)	1	n.a.
Extractable Zn	(HCl)(ppm)	663	95
Extractable Pb	(HCl)(ppm)	1819	15

TABLE 3.8

CHEMICAL AND PHYSICAL PROPERTIES OF IRON TAILINGS
IN OXIDIZED AND UNOXIDIZED STATES

<u>PROPERTY</u>		<u>IRON TAILINGS</u>	
		<u>UNOXIDIZED</u>	<u>OXIDIZED</u>
Colour		gray-black 5Y3/1	orange-brown 10YR5/6
Texture		silt loam	silt loam
Particle Size: sand	(%)	33	20
silt	(%)	64	59
clay	(%)	3	21
Moisture Retention:			
field capacity	(%)	12	29
permanent wilting	(%)	<1	10
available water	(%)	11	19
pH		6.0	2.2
Exchange acidity	(meq/100g)	3.0	572
Active acidity	(t/1000t)	2.0	256
Residual acidity	(t/1000t)	1121	178
Total 5	(%)	34	7.3
CEC	(meq/100g)	1.1	5.1
Exchangeable Ca	(meq/100g)	7.0	4.8
Exchangeable Mg	(meq/100g)	1.4	1.5
ECe	(mmhos/cm)	2.6	18
Water soluble Ca	(meq/l)	703	404
Water soluble Mg	(meq/l)	170	247
Water soluble Cl	(meq/l)	675	10
SAR		0.23	0.23
Saturation Percentage		27	54
Extractable Fe	(NH ₄ OAc) (ppm)	2050	9363
Extractable Mn	(CaCl ₂) (ppm)	42	154
Extractable Al	(CaCl ₂) (ppm)	<2	90
Extractable Zn	(HCl) (ppm)	625	111
Extractable Pb	(HCl) (ppm)	4400	68

TABLE 3.9

VARIATION OF CERTAIN PHYSICAL AND CHEMICAL PROPERTIES OVER THE
SURFACE OF THE SILICEOUS AND IRON TAILING PONDS

<u>PROPERTY</u>		<u>MEAN</u>	<u>RANGE</u>	<u>n</u>
<u>1. Siliceous Tailing</u>				
Colour		10YR5/6	10YR4/2-10YR7/8	6
Structure		granular	granular	6
pH		2.3	2.1-2.5	6
ECe	(mmhos/cm)	6	4-100	6
Total S	(%)	5.5	3-7	6
Active acidity	(t/1000t)	18	15.2-22.8	6
Residual acidity	(t/1000t)	170	93-218	6
<u>2. Iron Tailings</u>				
Colour		10YR5/6	--	69
pH		2.5	1.8-5.3	69
ECe	(mmhos/cm)	13	2-64	69
Total S	(%)	13.2	0.7-33	69
Residual acidity	(t/1000t)	442	30-1030	69

TABLE 3.10

PERCENT OF TAILINGS SURFACE WITH POTENTIALLY SEVERE GROWTH LIMITING FACTORS

<u>PROPERTY</u>	<u>RANGE</u>				
pH	1 - 3	3 - 5	5 - 7		
% Distribution	<u>85</u>	<u>14</u>	<u>1</u>		
ECe (mmhos/cm)	<4	4 - 6	6 - 10	10 - 15	>15
% Distribution	<u>4</u>	<u>4</u>	<u>31</u>	<u>24</u>	<u>37</u>
Total S (%)	<1	1 - 5	5 - 20	>20	
% Distribution	<u>2</u>	<u>17</u>	<u>54</u>	<u>27</u>	
Residual Acidity (t/1000t)					
% Distribution	<u><30</u>	<u>30 - 150</u>	<u>150 - 600</u>	<u>>600</u>	
	<u>2</u>	<u>17</u>	<u>54</u>	<u>27</u>	

TABLE 3.11

VARIATION OF CERTAIN CHEMICAL AND PHYSICAL PROPERTIES OF OXIDIZED SILICEOUS TAILINGS WITH DEPTH

<u>n</u>	<u>DEPTH</u> <u>(cm)</u>	<u>COLOUR</u>	<u>STRUCTURE</u>	<u>pH</u>	<u>E_{ce}</u> <u>(mV/cm)</u>	<u>TOTAL S</u> <u>(%)</u>	<u>ACIDITY</u> <u>(g/1000g)</u>	<u>RESIDUAL</u> <u>ACIDITY</u> <u>(g/1000g)</u>
2	0 - 20	10YR6/6	granular	2.2	11	5.4	20.3	210
2	20 - 40	10YR6/6	blocky	2.9	11	6.1	16.2	190
2	40 - 60	2.5Y7/6	blocky (sat'd)	2.7	19	4.4	19.5	138
2	60 - 80	5Y6/2	granular (sat'd)	3.6	19	8.6	21.2	269

TABLE 3.12

VARIATION OF CERTAIN CHEMICAL AND PHYSICAL PROPERTIES OF OXIDIZED IRON TAILINGS WITH DEPTH

n	DEPTH (cm)	pH		ECe		TOTAL S		RESIDUAL ACIDITY	
		$\bar{x}$	RANGE	$\bar{x}$	RANGE (mmhos/cm)	$\bar{x}$	RANGE (%)	$\bar{x}$	RANGE (t/1000t)
9	0 - 15	3.1	1.8 - 5.8	15	3 - 63	13	2 - 34	403	56 - 1062
7	15 - 30	3.7	2.0 - 5.4	20	7 - 36	19	3 - 33	588	84 - 1043
3	30 - 45	4.2	3.0 - 4.8	25	15 - 34	25	9 - 34	765	270 - 1074

TABLE 4-1
TOTAL ELEMENTAL ANALYSIS OF SINKLET WEATHERED IRON AND SILICEOUS TAILINGS

	Cu	Mg	Mn	K	Ca	Na	Mo	NI	Pb	Yt	Zn	Fe	Al	Si	Cr
1. Distilled Water Weathered															
Iron Tailing															
Fresh	0.01	0.88	0.21	0.33	0.03	0.13	<.01	<.01	0.64	0.1	0.43	37	1.8	5	.004
Bottom	<.01	0.83	0.19	0.30	0.04	0.13	<.01	<.01	0.51	0.1	0.42	36	1.7	4	.004
Oxidized															
Top	<.01	0.23	0.09	0.12	0.02	0.11	<.01	<.01	0.32	0.2	0.17	38	0.8	3	.001
Bottom	<.01	0.21	0.21	0.22	0.02	0.10	<.01	<.01	0.51	0.1	0.15	36	0.8	3	.001
Siliceous Tailing															
Oxidized	0.02	1.20	0.77	1.16	0.01	0.52	<.01	<.01	0.44	0.5	0.18	16	5.2	16	.003
Bottom	0.03	1.17	0.78	1.17	0.01	0.51	<.01	<.01	0.51	0.6	0.18	16	5.1	16	.001
2. 0.3 N Acetic Acid Weathered															
Iron Tailing															
Fresh	0.01	0.95	0.21	0.31	<.01	0.13	<.01	<.01	0.52	0.2	0.45	35	2.0	6	.001
Bottom	0.01	0.85	0.20	0.26	0.03	0.12	<.01	<.01	0.47	0.2	0.45	39	1.8	5	.001
Oxidized															
Top	0.01	0.21	0.13	0.18	0.02	0.10	<.01	<.01	0.08	0.2	0.18	36	1.0	3	.001
Bottom	<.01	0.22	0.09	0.15	0.01	0.11	<.01	<.01	0.33	0.1	0.18	37	0.8	3	.001
Siliceous Tailing															
Oxidized	0.03	1.15	0.81	1.22	0.01	0.46	<.01	<.01	0.08	0.5	0.18	16	5.2	17	<.001
Bottom	0.06	1.13	0.69	1.18	0.01	0.43	<.01	<.01	0.50	0.5	0.17	15	4.9	15	<.001
3. Original Tailing															
Iron Tailing															
Fresh	0.08	1.07	0.27	0.38	0.05	0.17	<.01	0.02	0.59	0.2	0.48	45	2.3	2	.001

NOTE: Bottom refers to the lower 5 cm of tailings in the Sinklet thimble; the Top is the remainder.

TABLE 4-2
AVAILABLE NUTRIENTS IN SOULET WEATHERED IRON AND SILICEOUS TAILINGS

	pH		Available				Available with 0.1 M HCl						
	H ₂ O	CaCl ₂	Ca	Ng	K	—	Cu	Zn	Fe	Mn	Pb	Co	—
			—	(ppm)			—	—	—	(ppm)	—	—	
1. Distilled Water Weathered													
Iron Tailing													
Fresh	3.8	3.9	37	35	12		45	1160	30480	472	166	7.7	10
Top	3.4	3.5	24	27	8		21	1360	31980	159	148	6.6	10
Bottom	4.4	4.4	2	23	5		14	7	230	325	1779	<0.1	<1
Oxidized	3.9	3.9	11	22	2		5	4	230	25	3449	<0.1	<1
Siliceous Tailing													
Oxidized	4.6	4.2	5	110	17		19	18	270	174	2749	<0.1	<1
Top	4.2	4.0	14	105	23		7	12	310	162	2269	<0.1	<1
Bottom													
2. 0.3 N Acetic Acid Weathered													
Iron Tailing													
Fresh	2.7	3.1	11	11	3		5	2040	43980	119	84	7	15
Top	4.1	3.8	6	7	12		27	1170	32980	116	134	7	12
Bottom	3.5	3.8	2	2	1		3	1	260	5	71	<0.1	<1
Oxidized	3.5	3.7	48	3	35		3	2	370	6	2149	<0.1	<1
Bottom													
Siliceous Tailing													
Oxidized	3.3	3.9	<1	8	12		2	2	320	29	69	<0.1	1
Top	3.7	3.9	2980	11	20		3	2	320	61	263	0.3	2
Bottom													
3. Original Tailing													
Iron Tailing													
Fresh	4.3	4.0	3350	263	65		104	354	15000	238	44	2.3	3.5
Bottom													

1. Bottom refers to the lower 5 cm of tailings in the Soulet thimble; the top is the remainder.

TABLE 4-3

EXTRACTABLE Fe, Al, Si, Mn CONCENTRATION IN SONNET WEATHERED AND UNWEATHERED TAILINGS

	Sulfate Pyrophosphate				Acid Ammonium Oxalate				Citrate Bicarbonate Dithionite			
	Fe	Al	Si	Mn	Fe	Al	Si	Mn	Fe	Al	Si	Mn
1. Distilled Water Weathered Iron Tailing												
Fresh												
Top ¹	4100	20	<100	5	41200	264	360	35	52500	525	250	78
Bottom	4200	20	<100	36	37600	304	240	16	52500	625	250	58
Oxidized												
Top	60	20	<100	<1	4040	96	120	2.4	127500	775	500	88
Bottom	50	10	<100	<1	3600	100	80	1.6	120000	600	500	85
Siliceous Tailing												
Oxidized												
Top	60	100	200	<1	2200	288	280	13	72500	2025	750	305
Bottom	120	150	1500	<1	3240	364	280	10	90000	1900	1750	363
2. 0.3 M Acetic Acid Weathered Iron Tailing												
Fresh												
Top	32000	110	<100	2	40000	392	120	9	50500	25	<250	13
Bottom	19000	30	<100	1	33600	232	120	7	64250	25	<250	40
Oxidized												
Top	200	20	<100	3	6400	156	<10	2	14200	750	<250	130
Bottom	190	20	<100	2	8800	152	<10	2	122500	675	1000	125
Siliceous Tailing												
Oxidized												
Top	230	290	<100	<1	3080	528	80	4	107500	25	750	588
Bottom	290	260	1600	3	4000	600	80	5	99000	25	2500	563
3. Original Tailing Iron Tailing												
Fresh												
Top	7000	10	<100	126	42800	480	560	244	48750	325	500	200
Bottom	280	110	200	4	104000	372	400	33	175000	400	1500	148
Oxidized												
Top	950	100	3300	16	23600	620	360	54	102500	925	2500	530
Bottom												

1. Bottom refers to lower 5 cm of tailings material in the Sonnet thimble; the top is the remainder.

TABLE 4-4
CHEMICAL ANALYSIS OF LEACHATE OF SUNGLASS WEATHERED IRON AND SILICIOUS TAILINGS

	Week 1	pH	Cu	Mg	Na	K	Cd	Co	Cr	Cu (ppm)	Mn	NI	Pb	Zn	Fe	Al	SI
1. Distilled Water Weathered Iron Tailing																	
Fresh	1	4.3	246	900	38	324	0.06	1.4	0.08	0.20	326	2.6	<0.2	1300	7200	<0.2	195
Oxidized	3	4.0	408	27	17	30	<0.02	<0.2	<0.02	<0.02	9	<0.2	1.0	4	152	<0.2	180
	1	1.0	343	504	39	85	0.84	3.4	0.66	38	60	5.0	9.1	360	5682	307	296
	3	2.1	2	65	21	19	<0.03	<0.03	<0.03	0.1	7	0.7	9.1	9	157	1	341
Silicious Tailing																	
Oxidized	1	1.7	644	822	28	478	0.36	1.1	0.33	4.8	114	2.5	9.7	192	533	289	1811
	3	2.5	706	431	45	160	0.06	<0.3	<0.03	0.06	16	1.4	12.5	1	156	1	1222
2. 0.3 N Acetic Acid Weathered Iron Tailing																	
Fresh	1	5.7	840	772	32	372	0.10	0.8	0.12	0.04	302	0.6	<0.2	1	11000	<0.2	<2
Oxidized	3	5.7	36	31	26	39	0.08	0.4	0.04	0.04	9	0.2	<0.2	1	8400	<0.2	<2
	1	0.9	409	455	26	241	0.45	2.3	0.41	42	64	3.0	8.6	227	7864	334	477
	3	3.4	25	177	28	54	<0.02	<0.2	0.09	0.11	37	0.5	21.0	38	818	24	814
Silicious Tailing																	
Oxidized	1	1.9	650	1100	44	405	<0.03	0.8	0.33	11	155	1.3	11	228	1938	125	275
	3	3.4	700	268	34	95	<0.03	<0.3	<0.03	2	38	<0.3	18	14	480	33	625

NOTE: 1. Week 1 and 3 refer to the solution removed from the collecting flask after 1 week and after 3 weeks of weathering.

TABLE 5.1

EFFECT OF LINE RATE ON VEGETATIVE GROWTH, SPECIES COMPOSITION AND METAL CONTENT OF
VEGETATION ESTABLISHED ON OXIDIZED SILICEOUS TAILING

Plant CaCO ₃ Rate	Population		Biomass	Species Cover						Metal Content	
	Grass	Legume		Vegetative Cover	Tall Wheatgrass	Crested Wheatgrass	Red Top	Birdsfoot Trefoil	Pb	Zn	
1. 1980 Growing Season											
98	11.3	0.3	-	18	8	9	-	0	-	-	
195	9.2	0.8	-	5	2	4	-	0	-	-	
293	7.8	1.3	-	3	1	2	-	0.2	-	-	
390	5.1	1.1	-	2	<1	1	-	0.1	-	-	
2. 1981 Growing Season											
98	4	<1	3555	49	19	19	3	0	113	73	
195	5	<1	3615	46	1	15	16	8	79	49	
293	5	<1	2970	37	0	1	16	7	53	48	
390	4	<1	660	13	1	<1	6	2	54	58	

TABLE 5.2

CHANGE IN pH AND ECe OF LINED OXIDIZED SILICEOUS TAILINGS WITH TIME

<u>CaCO₃</u> <u>Rate</u> <u>(t/ha-15cm)</u>	<u>Growing Season</u>					
	<u>1978</u>	<u>1979</u>	<u>1980</u>	<u>1981</u>	<u>1982</u>	<u>1983</u>
1. <u>Tailings pH</u>						
1.1 <u>0-15 cm depth: pre-lime pH 3.5</u>						
98	8.3	7.1	7.5	4.8	4.0	3.4
195	11.6	8.2	8.1	6.8	7.2	7.3
293	12.2	9.0	10.1	8.3	7.4	7.8
390	12.0	10.7	10.4	7.6	7.4	7.8
1.2 <u>15-30 cm depth</u>						
98	-	5.3	6.1	3.4	-	-
195	-	6.8	5.1	5.4	-	-
293	-	7.7	6.0	6.1	-	-
390	-	7.3	5.1	7.2	-	-
2. <u>Tailings ECe (mmhos/cm)</u>						
2.1 <u>0-15 cm depth</u>						
98	2	3	4	4	3	4
195	5	3	4	3	2	4
293	9	4	6	4	2	4
390	13	6	5	3	3	5
2.2 <u>15-30 cm depth</u>						
98	-	3	4	3	-	-
195	-	2	3	4	-	-
293	-	3	4	3	-	-
390	-	3	3	3	-	-

TABLE 5.3

CONIFER AND MAMMOTH WILDRIE TRANSPLANT
SURVIVAL ON LIMED OXIDIZED SILICEOUS TAILINGS

<u>CaCO₃</u> <u>Rate</u> (t/ha)	<u>Percent Survival</u>			
	<u>1980</u>	<u>1981</u>	<u>1982</u>	<u>1983</u>
1. <u>Mammoth Wildrye</u> ¹				
98	93	90	-	-
195	98	98	-	-
293	98	98	-	-
390	93	83	-	-
2. <u>Lodgepole Pine</u> ²				
98			20	20
195			40	40
293			100	100
390			80	60
3. <u>Engelmann Spruce</u>				
98			40	40
195			80	60
293			80	60
390			80	80
4. <u>Douglas Fir</u>				
98			40	40
195			80	60
293			60	40
390			40	40
5. <u>Ponderosa Pine</u>				
98			0	0
195			0	0
293			0	0
390			60	60

NOTE: 1. 40 plugs of mammoth wildrye transplanted on each lime rate.
 2. 5 seedlings of each conifer specie planted on each lime rate treatment.

TABLE 9-4

VARIATION IN VEGETATION WITH LINE RATE AND TAILING VARIABILITY ON LINED OXIDIZED SILICEOUS TAILING

Parameter	60				90				120			
	Mix 1		Mix 2		Mix 1		Mix 2		Mix 1		Mix 2	
	South	North	South	North	South	North	South	North	South	North	South	North
Number sample sites	7	3	7	3	6	4	7	3	6	4	5	5
Tailing pit: %	2.6	2.1	5.4	2.0	4.6	2.4	7.1	2.7	6.3	4.9	6.0	4.1
range	2.0-4.3	2.0-2.3	2.0-7.8	2.0-2.1	1.9-7.7	2.0-3.4	2.4-7.8	2.6-2.9	2.7-7.5	2.2-7.5	2.8-7.7	1.6-7.2
Tailing ECo(mhos/cm): %	0	0	57	0	50	0	71	0	83	50	80	20
range	4-8	8-10	4-9	8-9	4-8	6-9	4-7	4-6	4-6	4-6	4-6	6-13
Vegetative cover: (\$)	100	66	66	66	100	75	100	100	100	100	100	80
\$ 5 and lower	57	0	100	0	67	25	71	0	83	75	100	80
\$ 5 with vegetation	15	0	45	0	29	10	49	0	68	22	23	7
range	4-40		1-45		5-40	10	5-60		40-100	20-25	5-35	3-15
\$ 5 with vegetation	57	0	86	0	67	25	71	0	83	75	100	80
range	485	0	1378	0	1160	310	1376	0	1285	1235	314	100
Species Cover (\$)	90-1570		150-2510		10-1920	310	50-2060		860-2650	850-1890	30-760	20-320
Birdfoot trefoil:												
frequency(\$)	0	0	71	0	33	0	57	0	83	0	60	40
range			10		4		28		37		14	1
frequency(\$)	29	0	100	0	67	0	71	0	83	75	100	60
range	14		33		17		26		14	10	14	7
frequency(\$)	2-25		1-65		2-25		5-50		5-25	5-13	5-20	3-13
Red top												
frequency(\$)	29	0	71	0	67	25	43	0	83	75	60	40
range	10		6		10	10	3		16	11	2	2
frequency(\$)	5-15		3-10		3-15	10	2-5		5-30	7-20	1-3	1-5
Canada bluegrass												
frequency(\$)	15	0			0	0			0	0		
range	1											
Crested bluegrass												
frequency(\$)	43	0			17	0			17	0		
range	2-4				1				5	0		

TABLE 5.5

VARIATION IN CONIFER-GRASS TRANSPLANT SURVIVAL AND TAILINGS pH - ECE

BETWEEN NORTH AND SOUTH HALVES OF DEMONSTRATION AREA

Sub-Plot	Transplant Survival Plot					Tailings	
	Ponderosa Pine	Lodgepole Pine	Douglas Fir	Hammoth Wildrye	Tufted Hairgrass	pH	ECe (mmhos/cm)
1. 60 t/ha CaCO ₃							
South: 1	28	52	36	44	36		
2	28	76	36	56	28		
$\bar{x}$	<u>28</u>	<u>64</u>	<u>36</u>	<u>50</u>	<u>32</u>	4.0	5.5
North: 1	0	0	0	16	0		
2	0	0	0	0	0		
$\bar{x}$	<u>0</u>	<u>0</u>	<u>0</u>	<u>8</u>	<u>0</u>	2.1	8.3
2. 90 t/ha CaCO ₃							
South: 1	64	68	60	92	48		
2	20	64	40	76	12		
$\bar{x}$	<u>42</u>	<u>66</u>	<u>50</u>	<u>84</u>	<u>30</u>	5.7	5.0
North: 1	0	0	0	0	0		
2	0	24	0	36	16		
$\bar{x}$	<u>0</u>	<u>12</u>	<u>0</u>	<u>13</u>	<u>8</u>	2.6	6.5
3. 120 t/ha CaCO ₃							
South: 1	52	72	84	88	72		
2	40	68	48	96	36		
$\bar{x}$	<u>46</u>	<u>70</u>	<u>66</u>	<u>92</u>	<u>54</u>	6.1	4.2
North: 1	0	4	0	60	8		
2	20	20	4	28	28		
$\bar{x}$	<u>10</u>	<u>12</u>	<u>2</u>	<u>44</u>	<u>18</u>	4.4	6.5

NOTE: 1. Subplots 1 & 2 are within the south half of the experimental plot; subplots 3 & 4 are within the north half of the main plot.

TABLE 5-6

VARIATION IN OXIDIZED SULFUROUS TAILING pH AND ECD WITH LINE RATE AND TIME

		0			60			90			120		
		1981	1982	1983	1981	1982	1983	1981	1982	1983	1981	1982	1983
1. Tailing pH													
Line Rate (t/hr-15cm)													
$\bar{x}$		2.9	2.3	2.6	5.4	4.2	3.4	5.9	3.8	4.4	7.4	6.3	5.4
range		2.6-3.5	1.7-3.7	2.0-4.3	3.4-7.4	1.9-7.2	2.0-7.8	4.0-7.7	2.1-7.5	1.9-7.8	6.2-8.0	4.5-7.5	1.6-7.7
n		10	10	10	10	10	20	10	10	20	10	10	20
\$ pH-5		0	0	0	60	40	20	80	20	40	100	80	60
>7		0	0	0	10	10	20	20	10	30	80	40	40
2. Tailing ECD (meq/cm)													
$\bar{x}$		4	6	6	3	5	6	3	7	6	3	5	5
range		3-9	4-7	6-9	3-4	2-9	4-10	3-4	2-11	4-9	3	2-9	4-13
n		10	10	10	10	10	20	10	10	20	10	10	20
\$ ECD-8		0	0	10	0	40	30	0	40	10	0	10	5
>16		0	0	0	0	0	0	0	0	0	0	0	0

TABLE 5.7

EFFECT OF LINE RATE ON VEGETATIVE GROWTH, SPECIES COMPOSITION AND METAL CONTENT OF

VEGETATION ESTABLISHED ON OXIDIZED IRON TAILING

CaCO ₃ Rate (t/ha)	Plant Population		Biomass (kg/ha)	Vegetative Cover	Species Cover				Metal Content		
	Grass	Legume			Canada Bluegrass	Tall Wheatgrass	Crested Wheatgrass	Red Top	Birdsfoot Trefoll	Pb	Zn
	(m/0.1m ²)							(ppm)			
1. 1980 Growing Season											
				(\$)							
90	2.1	0.1	-	1	-	0	1	-	0	-	
180	5.4	2.5	-	3	-	1	2	-	<1	-	
270	6.1	6.1	-	2	-	0	2	-	<1	-	
360	3.9	6.2	-	2	-	0	2	-	1	-	
2. 1981 Growing Season											
90	0	0	0	0	0	0	0	0	0	-	
180	3	0	730	18	3	2	2	7	<1	83	
270	2	<1	345	11	4	<1	0	4	<1	59	
360	3	<1	270	7	3	0	0	2	<1	58	
										40	
										43	
										51	

TABLE 5.8

CHANGE IN pH AND ECe OF LIMED OXIDIZED SILICEOUS TAILINGS WITH TIME

<u>CaCO₃ Rate (t/ha-15cm)</u>	<u>Growing Season</u>					
	<u>1978</u>	<u>1979</u>	<u>1980</u>	<u>1981</u>	<u>1982</u>	<u>1983</u>
1. <u>Tailings pH</u>						
1.1 <u>0-15 cm depth: pre-lime pH 1.9</u>						
90	6.5	1.9	3.4	2.2	1.4	2.4
180	8.2	5.2	7.4	4.5	3.9	2.5
270	11.9	8.5	8.1	7.5	6.6	3.4
360	11.3	9.5	9.4	7.6	7.1	2.7
1.2 <u>15-30 cm depth</u>						
90	-	1.7	2.3	2.2	-	-
180	-	1.7	2.3	2.7	-	-
270	-	1.8	2.5	3.3	-	-
360	-	1.6	7.7	5.0	-	-
2. <u>Tailings ECe (mmhos/cm)</u>						
2.1 <u>0-15 cm depth</u>						
90	6	10	9	7	10	10
180	3	6	5	5	6	8
270	5	2	5	3	2	6
360	4	4	7	3	3	7
2.2 <u>15-30 cm depth</u>						
90	-	11	10	9	-	-
180	-	11	10	4	-	-
270	-	11	9	4	-	-
360	-	11	6	4	-	-

TABLE 5.9

CONIFER AND MAMMOTH WILDRIE TRANSPLANT
SURVIVAL ON LIMED OXIDIZED SILICEOUS TAILINGS

<u>CaCO₃</u> <u>Rate</u> (t/ha)	<u>Percent Survival</u>			
	<u>1980</u>	<u>1981</u>	<u>1982</u>	<u>1983</u>
1. <u>Mammoth Wildrye</u> ¹				
90	35	5		
180	65	63		
270	90	83		
360	75	83		
2. <u>Lodgepole Pine</u> ²				
180			20	0
270			40	0
360			20	0
3. <u>Engelmann Spruce</u>				
180			0	0
270			20	0
360			20	0
4. <u>Douglas Fir</u>				
180			20	0
270			0	0
360			0	0
5. <u>Ponderosa Pine</u>				
180			0	0
270			0	0
360			0	0

NOTE: 1. 40 plugs of mammoth wildrye transplanted on each lime rate.
 2. 5 seedlings of each conifer specie planted on each lime rate treatment except 90 t/ha-15 cm.

TABLE 5.10 VARIATION IN VEGETATION GROWING ON OVERBURDEN OF VARYING DEPTH OVER FLOAT ROCK - IRON TAILINGS

1982 Growing Season												
1.	Seed Mix 1 x range frequency(%)	Vegetative Cover (%)		Legume Cover (%)		Legume Content (%)		Grass Cover (%)			Litter Cover (%)	Biomass (kg/ha)
								Crested Wheatgrass	Other			
		55	<1	0 - 1	0 - 2	<1	0 - 1	54	0 - 1	5 - 30	18	1156
		0 - 85	20	0 - 1	0 - 2	0 - 2	0 - 1	0 - 84	0 - 1	5 - 30	5 - 30	0 - 2070
		90	20	20	-	-	-	90	50	100	100	90
2.	Seed Mix 2 x range frequency(%)	64	22	2 - 40	8 - 44	31	10 - 35	22	18	5 - 40	19	1353
		25 - 90	100	100	-	-	-	7 - 50	100	5 - 40	5 - 40	130 - 2510
		100	100	100	-	-	-	100	100	100	100	100
1983 Growing Season												
1.	Seed Mix 1 x range frequency(%)	Vegetative Cover (%)		Legume Cover (%)		Legume Content (%)		Grass Cover (%)			Litter Cover (%)	Biomass (kg/ha)
								Crested Wheatgrass	Other			
		55	0	0 - 1	0 - 2	<1	0 - 1	55	0	20 - 40	27	2652
		40 - 80	100	0	0	0	0	40 - 80	0	20 - 40	20 - 40	2010 - 3520
		100	0	0	0	0	0	100	0	100	100	100
2.	Seed Mix 2 x range frequency(%)	65	11	5 - 15	6 - 25	7	5 - 20	44	11	20 - 30	22	3531
		50 - 80	100	100	100	100	100	30 - 70	5 - 20	20 - 30	20 - 30	1770 - 4750
		100	100	100	100	100	100	100	100	100	100	100

Seed Mix Composition: No. 1 sainfoin 50%, fairway crested wheatgrass 25%, russian wildrye 25%.
No. 2 rambler alfalfa 40%, nordan crested, wheatgrass 40%, durar hard fescue 20%.

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TAILINGS MANAGEMENT STUDY

COAST COPPER CO.

PART FIVE - REVEGETATION

1. Purpose
2. Reclamation Objective
3. Revegetation Technology
 - 3.1 Environmental Setting
 - 3.2 Climate
 - 3.3 Mineralogical, Chemical and Physical Properties
 - 3.4 Growth Limiting Factors
 - 3.5 Revegetation Research
4. Operational Revegetation

1. PURPOSE

The Coast Copper mine ceased operation in January 1973 after 10 years of production. Land disturbance totalled 11 ha including 9 ha of plant site and waste rock dumps and 2 ha of tailing. Normally tailing were pumped to Benson Lake, mixed with a flocculating agent and deposited on the lake bottom. However, during interruption in the normal system of lake disposal, tailing were deposited on land in a small impoundment area adjacent the Benson River. Tailing revegetation was initiated to improve aesthetics and meet requirements of surface work permit M-63.

2. RECLAMATION OBJECTIVES

The objective of reclamation at the Coast Copper mine was to improve the plant growth environment on waste disposal and other disturbed areas to encourage regeneration of native vegetation. Establishment of an initial vegetative cover of grass and legume species would stabilize surfaces, improve aesthetics, accelerate normal "soil" development and provide forage for wildlife.

3. REVEGETATION TECHNOLOGY

A revegetation research program was active at the Coast Copper mine between 1973 and 1978. Progress was reported annually to the Senior Reclamation Inspector, B.C. Ministry of Energy, Mines and Petroleum Resources. In 1975 the Dept of Soil Sciences, U.B.C. conducted field and laboratory investigations under a program sponsored by the Ministry of Energy, Mines and Petroleum Resources.

3.1 Environmental Setting

The Coast Copper mine was located at the north end of Vancouver Island some 40 km southwest of Port McNeil, B.C. The mine and mill complex was situated on an east facing slope above the Benson River at an elevation of 150 m. The mine site is within the Vancouver Island mountains which are the southern section of the Insular Mountains. The maximum elevations of peaks near the mine are less than 465 m. Surficial deposits consist of tills and glacial-fluvial deposits. The area was classified as the Coastal Western Hemlock biogeoclimatic zone. Podzolic soils are formed beneath the vast western hemlock forests. The Benson River valley was classed as "important" winter range for black-tailed deer but had severe limitations for the production of waterfowl. Outdoor recreation capability was moderately low. Present land use in the area was reported to include mines, quarries, gravel pits and mature and immature productive woodland. Of 2100 hectares within a 2.5 km radius of the mine, 73% was undisturbed "woodland" and water bodies while 24% was clear-cut logged, 2.5% was affected by mining and the remainder was access roads. The tailing deposit was 0.1% of the total area.

3.2 Climate

The climate is classified as a Marine West Coast climate and is characterized by moderate winter temperatures and high annual precipitation. Mean winter and summer temperatures are -7 C and 18 C, respectively. Annual precipitation averages 320 cm mainly occurring from October to January. Snowfall is generally light. Frost free period and growing season average 175 days and 220 days, respectively. Growing degree days average 2300.

3.3 Mineralogical Chemical and Physical Properties of Tailing

Tailings were sampled and analyzed for various properties on several occasions between 1972 and 1978. Recently deposited tailings were sampled in June 1972 for laboratory and growth

room investigations. Based on results of these preliminary studies the tailing deposit was seeded to a grass-legume mixture and fertilized in April 1973. Variable vegetation establishment, subsequent deterioration of vegetation and changes in the physical appearance of the tailings prompted more intensive sampling and analysis in 1974, 1975 and 1978. Tailings were also sampled and analyzed by the Department of Soil Science, U.B.C.

3.31 Mineralogical Properties

The main mineral constituents of tailings include magnetite 35%, pyrrhotite 10%, andesine 20% together with calcite, garnet, and epidote. A typical sample of fresh tailings assayed 34% Fe, 3% S and 0.1% Cu.

Dominant tailing minerals as identified by x-ray diffraction of mines 200 mesh size fraction material included chlorite, anyahibole, feldspar, quartz and gypsum (1).

3.32 Chemical Properties

Certain chemical properties of surface tailings sampled in 1972 are presented in Tables 3.1, 3.2, 3.3 and 3.4. Tailings were recently deposited. Two samples were taken near the pond inlet and two were from the opposite side of the pond near the dyke.

Surface tailings varied in appearance with deposits near the inlet coarse-textured and rust coloured while depressional areas adjacent the dyke contained finer textured, light grey coloured tailings. Throughout the central area of the pond were moderately coarse, dark grey coloured tailings. White coloured precyactates were common on the surface.

In 1972 surface tailings were near neutral in reaction, slightly saline, devoid of decomposing plant residues, deficient in plant available N, P, K and possibly Mg. Cation exchange capacity was low with Ca the dominant cation. Exchange acidity and lime requirement were also low. Extractable Mn, Cu, Fe and Zn were elevated relative to a normal agricultural soil.

By 1975 oxidation and weathering caused significant changes in certain chemical properties which affect tailing revegetation potential (Table 3.5). Specifically, pH and ECe of surface samples, collected at 22 grid points set 16 m apart across the entire pond area, averaged 3.3 and 11 mmhos/cm, respectively. pH ranged widely from 2.5 to 7.5; however, 87% of sample sites had pH of 5 or less while 60% had pH of 3 or less (Table 3.6). Tailing ECe also ranged widely from 2 to 26 mmhos/cm.

Four tailing profiles were also sampled to assess variation in certain chemical properties with depth (Table 3.7). Profile sites were located within areas of varying structure and vegetative cover as described:

- a) a non-vegetated, coarse textured tailing area,
- b) a non-vegetated, medium textured tailing area,
- c) a sparsely vegetated medium textured tailing area, and
- d) a densely vegetated fine textured slimes area.

The depth of oxidation and associated deterioration in growing conditions varied with site. A hard, cemented layer developed at 5 cm depth within the coarse textured, non-vegetated area. Granular tailings above the cemented layer were extremely acid i.e pH 3.1. Medium textured tailings with no vegetation had developed an extremely acid reaction to a depth of 35 cm. At depths below 35 cm pH and total S increased sharply. Depth of oxidation was much shallower within areas of medium textured tailings with sparse vegetative cover. Extreme acidity and a platy structure had developed to a depth of only 5 cm. Below 5 cm, a reaction range suitable for plant growth was observed

which may explain the survival of a partial cover of vegetation. Growth conditions within the slimes area had not deteriorated significantly and a dense grass cover persisted. Tailing ranged from slightly to moderately saline. High annual precipitation should leach excess salts maintaining concentrations within the range tolerated by most grass species. However, formation of an impermeable layer at shallow depths within the profile may impede internal drainage and flushing of salts. A survey conducted in 1978 indicated that a hard layer occurred within 15 cm of the surface at 53% of the survey points, between 15 and 30 cm at 27% and deeper than 30 cm at 20%.

The Soil Science Dept, UBC also sampled tailing profiles in 1975. Total elemental analyses results are presented in Table 3.8. pH, cation exchange capacity, exchangeable cations, total N and S and available P values for four profiles are presented in Table 3.9. pH varied with profile and with depth. Cation exchange capacity was low relative to background soil i.e. 54 to 76 meq/100 g. Calcium was the dominant cation. Organic matter content was higher than expected when compared to the very low N contents. Available Ca, Mg and K content and soluble salt content and composition are presented in Table 3.10. Calcium was abundant but decreased drastically with decreasing pH. Mg and K were low. Tailings were slightly to moderately saline. Calcium was the dominant cation in solution while sulfate was the dominant anion. Magnesium was also significant. Available Cu, Fe and Zn varied widely within a single profile (Table 3.11).

3.33 Physical Properties

Particle size analysis data presented in Table 3.12 illustrate the variability in distribution of sand and silt sized particles occurring during tailing deposition. The clay size fraction was consistently low. Available water storage capacity varied with texture ranging from 21 to 35% for silt loam tailing, 13% for sandy loam tailing and only

4% for loamy sand tailing (Table 3.13).

Bulk and particle densities were high relative to normal soil. With silt loam textured slimes aeration at field capacity moisture content was only 8%. Plant growth and root development on slimes may be limited by poor aeration.

Saturated hydraulic conductivity was also low indicating inyseded internal drainage probably due to the development of impermeable layers near the tailing surface.

3.34 Plant Growth Limiting Factors

Growth room and field studies conducted during 1973 and 1974 confirmed that vegetation would establish on fresh recently deposited tailing provided N, P and K were applied as fertilizer. However, rapid deterioration of vegetation established in the 1973 operational seeding program indicated development of severe plant growth limiting conditions as tailings weathered and oxidized. Subsequent analyses of tailing associated deterioration with development of a strongly acid reaction, moderate to very strong salinity and formation of impermeable layers near the tailing surface. Only tailing slimes, which maintained a near neutral reaction, continued to sustain satisfactory vegetation.

3.34.1 Lime Requirement for Tailing Revegetation

The conventional agronomy approach to improving plant growth on acid soils is to apply agricultural grade limestone. Conventional soil analytical techniques for estimating liner requirement appear to underestimate quantities of limestone required to neutralize tailing "active" acidity and do not measure "residual" acidity resulting from continual oxidation of unreacted pyrrhotite in partially oxidized tailing. Lime requirement of coarse and medium textured tailing was

estimated at 5 and 12×10 ppm, CaCO_3 using the $\text{BaCl} - \text{TEA}$ technique. Maximum lime requirement, estimated from total S content of tailing, varies from 18 to 90×10 ppm for partially oxidized surface tailing and range up to 120×10 ppm for unoxidized tailing sampled at depth within the pond.

Growth room and field studies were initiated in 1976 to determine the amount of liming material required to maintain tailings within a reaction range suitable for plant growth. In the growth room study application of 40 mg CaCO_3 /g tailing raised tailing pH from 2.6 to 7.4 and maintained this near neutral reaction through a 34 week growth and incubation period. Red top, creeping red fescue, tall wheatgrass and western wheatgrass germinated and grew satisfactory on the limed tailing. A field application rate of 92 t CaCO_3 /ha-15 cm is equivalent to 40 mg CaCO_3 per gram tailings.

In the field study application of 54 t CaCO_3 /ha - 15 cm maintained medium textured tailing within a range of 7.1 to 7.6 through three growing seasons. Liming materials were applied as follows: 9 t CaCO_3 /ha as dolomitic limestone in April 1975 plus 45 t CaCO_3 /ha as agricultural grade hydrated lime in April 1976. The pH of coarse textured tailings limed with 20 t CaCO_3 /ha- 15 cm as dolomitic limestone in April 1975 had decreased to 4.7 by the end of the first growing season and was 2.8 when sampled in June 1978.

3.5 REVEGETATION RESEARCH

Field studies were initiated at two stages in the research program. The first study was initiated in 1973 on recently deposited tailings to determine nutrient requirements for establishing and sustaining gross vegetation. With oxidation of pyrrhotite and development of an acid tailing reaction vegetation deteriorated and the study was abandoned. A second study designed to

determine lime and nutrient requirements for revegetating rapidly oxidizing tailing was initiated in 1975.

In April of that year two plots were established, one on coarse tailings and the other on medium textured tailings. Dolomitic limestone was incorporated at 7, 13, and 20 t CaCO_3 /ha with coarse tailings and at 11, 22 and 33 t/ha with medium tailings. Within each lime rate phosphorus fertilizer was applied at four rates equivalent to 55, 110, 220 and 440 kg/ha P_2O_5 . Nitrogen and potassium were applied at 55 kg/ha to all treatments. Following incorporation of lime and fertilizer the plots were seeded to a mixture of grasses. Quantities of lime applied were not sufficient to neutralize tailing and grasses did not establish satisfactorily.

On April 20, 1976 agricultural grade hydrated lime was added to the plot on medium textured tailings to raise lime rates to the equivalent of 54, 81 and 105 t CaCO_3 /ha - 15 cm. On the same date, a second plot was established also on a medium textured tailings. Hydrated lime (83%) and dolomitic limestone (17%) were applied at 54, 83 and 110 t CaCO_3 /ha - 15 cm. Within each lime rate tri-superphosphate and muriate of potash were applied at rates equivalent to 0, 56, 168, 393 and 840 kg/ha P_2O_5 and 35 kg/ha K_2O . One month later a complete fertilizer supplying the equivalent of 46 kg/ha N, 56 kg/ha P_2O_5 and 35 kg/ha K_2O was broadcast on both plots just prior to seeding with a mixture of creosote red fescue (11%), red top (6%), tall wheatgrass (31%), western wheatgrass (31%) and birdsfoot trefoil (21%) at 105 kg/ha. A maintenance fertilizer application equivalent to 56 kg/ha N and K_2O was surface broadcast as urea, sulfur-coated urea and potassium magnesium sulphate in June 1977. Vegetative cover, species cover and biomass were assessed October 5, 1977 and June 21, 1978. Tailings were sampled on both dates to determine pH and ECe. Results are presented in Table 5.1.

Application of 54 t CaCO_3 /ha - 15 cm maintained tailing

reaction within a range tolerated by grasses and legumes through three growing seasons. Maximum vegetative cover and biomass were generally produced on tailing limed at the low rate. Application of 83 and 110 t CaCO_3 /ha increased tailing reaction to within the strongly alkaline range during the initial growing season but decreased to moderately alkaline by the third growing season. The strongly alkaline conditions which prevailed following seeding probably limited seedling establishment resulting in reduced vegetative cover and biomass in subsequent growing seasons. Lower vegetative cover and biomass on site 2 may be the result of the same phenomena since the total amount of lime was applied only one month before seeding. On site 1 lime application was split over two years. Limed tailings ranged from non-to-slightly saline which should not have limited vegetative growth appreciably.

Vegetation was dominated by grasses red top and creeping red fescue. The relative abundance of these two species varied with growing season as cover due to red top decreased with time. The general decrease in vegetative cover and biomass during 1978 may be due to discontinuation of maintenance fertilizer after the 1977 growing season.

The nutrient and metal content of vegetation growing on limed tailing was determined in 1978. Forage P, K and Mg concentrations were low relative to suggested typical values for fexue and red top grown on agricultural soils. In contract, forage was high in Ca. Forage P content was not affected by phosphorus fertilizer rate. Fe, Cu and Zn concentrations ranged from 1800 - 23,000 ppm Fe, 11 - 61 ppm Cu and 3 - 10 ppm Zn. Fe and Cu were slightly elevated relative to suggested typical concentrations for the same species grown on soils. Metal contents were not affected by lime or phosphorous rate.

A hard impermeable layer developed at a depth of 10 to 15 cm below the surface of the site 2 plot limiting

vegetative growth and cover relative to site 1.

Monitoring was discontinued after 1978 due to the sale of the Coast Copper mine.

4.

OPERATIONAL REVEGETATION

In April 1973 the tailing disposal area was seeded to a grass-legume mixture composed of alfalfa (22 kg/ha), timothy (11 kg/ha), creeping red fescue (17 kg/ha), tall fescue (33 kg/ha) and colonial beutgrass (2 kg/ha). Fertilizer supplying the equivalent of 33 kg/ha N, 165 kg/ha P2O5 and 55 kg/ha K2O was broadcast on the tailing surface prior to seeding. A post-emergent application of 88 kg/ha N, as slow release urea-formaldehyde, was made in early June 1973. In late April 1974, 55 kg/ha N, 55 kg/ha P2O5 and 28 kg/ha K2O was applied as maintenance. An additional 55 kg/ha N was applied as urea in mid-June 1974. A final maintenance application of 110 kg/ha N, 55 kg/ha P2O5 and 28 kg/ha K2O was made in May 1975.

Vegetation establishment in 1973 was variable with seedling populations, distribution and growth varying substantially. Dense, vigorous grass stands covered areas of fine textured tailing slimes. Coarse, rust coloured tailings near the pond in-let were devoid of surviving grass seedling. Wind blown tailings buried seedlings which had emerged. The major portion of the talings pond was covered by an unevenly distributed grass stand. Dense seedling populations occupied cracks and other depressions while smooth tailing surfaces were sparsely populated with small, severely chlorotic grass seedlings. Undissolved fertilizer granulaes remained on the crusty tailing surface four months after application. Pre-seeding tillage improved seedling distribution and growth.

In 1974, the second growing season, only 35% of the tailing area had a satisfactory vegetative cover. The

remaining area was either totally devoid of vegetation or sparsely covered with unevenly distributed grass stands. Slimes and other fine tailing fractions which accumulated in depressional areas had a dense cover of creeping red fexue and timothy. Tailing areas with less than satisfactory vegetative cover were either coarse-textured or tailings with a surface crust and patches of a white coloured precipitate. The latter material was characteristic of the largest area not satisfactorily revegetated. Small severely chlorotic grass plants emerging from desseeation cracks and other depressions in the tailing surface and patches of dead grass were common on this area.

In 1975, tailing vegetation was monitored using a grid sampling system in which vegetative cover and species cover were determined on 78 0.1 m quadrats located at 16 m intervals across the tailing pond surface. Biomass samples were taken at every fourth grid point. Nine biomass samples were analyzed for total N, P, K, Ca, Mg, S, Fe and Cu. As expected vegetation continued to be highly variable. Vegetative cover ranged from 0 to 100% but averaged only 29%. Fourty-eight percent of quadrats had no vegetative cover while only 29% had greated than 50% cover. Biomass ranged widely from 0 to 6360 kg/ha but averaged only 980 kg/ha. Sixty-eight percent had less than 1000 kg/ha biomass while only 18% had more than 2000 kg/ha. Maximum cover and biomass occured on areas of slimes accumulation. Creeping red fexue and tall fexue were dominant species on tailings areas with vegetative growth. Invasion of native herbaceous and woody species was minimal. Acid-tolerant mosses were growing in localized areas. Increased dieback of native species rooting in natural soil at shallow depth beneath the tailings was observed.

Nutrient and metal content of nine biomass samples were as follows:

	Mean	Range
	----	-----
N (%)	1.12	0.87-1.60
P (%)	0.05	0.02-0.10
K (%)	1.34	0.80-1.98
Ca (%)	0.36	0.20-0.84
Mg (%)	0.09	0.08-0.14
S (%)	0.19	0.14-0.26
Fe (ppm)	592	130-1800
Cu (ppm)	22	10-40

Creeping red fexue, sampled in 1975 by Dept. Soil Sciences, UBC contained the following nutrient and metal concentrations (1): N 0.75%; P 0.12%; K 1.41%; Mg 0.10%; Ca 0.15%; Na 174 ppm; Mn 220 ppm; Zn 162 ppm; Cu 6 ppm and Fe 42 ppm.

REFERENCES

- Lavkulich, L.M., et al. 1976. Pedological inventory of three sulphide mine areas in British Columbia. Dept. of Soil Science, U.B.C.

Table 3.1: pH, Total N, Available Plant Nutrient and Salinity of Coast Copper Tailings

	pH	ECe (mmhos/cm)	Total N (%)	Org. Matter (%)	Available Nutrients				
					NO ₃ -N	P	K (ppm)	Ca	Mg
1. <u>Coarse tailing</u>									
1	6.7	2.7	.001	.02	<1	<2	83	2140	36
2	6.4	2.4	.030	.60	<1	<2	52	1915	31
2. <u>Fine tailing</u>									
1	7.2	2.5	.028	.56	<1	<2	110	3502	60
2	7.3	1.7	.006	.12	3	2	85	3000	38

Table 3.2: Cation Exchange Capacity, Extractable Cations, Exchange Acidity and Lime Requirement of Coast Copper Tailings

	CEC (meg/100g)	<u>Ammonium Acetate Extr.</u>				Exchange Acidity	Lime Req't (ppm)
		<u>Ca</u>	<u>Mg</u>	<u>K</u>	<u>Na</u>		
		(meg/100g)					
<u>1. Coarse tailing</u>							
1	2.4	22.5	0.4	0.2	0.2	1.54	90
2	1.9	26.9	0.3	0.2	0.2	0.50	-627
<u>2 Fine tailing</u>							
1	2.6	56.3	0.8	0.3	0.2	0.61	-269

Table 3.3: Extractable Metal Concentration of Coast Copper Tailings

	0.2M CaCl ₂ Ext		pH 4.8, Amm. Acetate Ext.		0.1N HCl Ext		
	Mn	Al	Cu	Fe	Zn	Pb	Cd
	(ppm)		(ppm)		(ppm)		
<u>1. Coarse tailing.</u>							
1	4.0	<2	7	165	4	<5	0
2	5.6	<2	4	185	10	<5	0
<u>2 Fine tailing:</u>							
1	2.8	<2	5	205	15	<5	0
<u>3 Normal soil:</u>							
	0.3	<2	<0.1	0.5	3	<5	0

Table 3.4: Concentration and Composition of Water Soluble Salts in Recently Deposited Fine Tailings

ECe (mmhos/cm)	Water Soluble Ions					SAR	Sat'n. %
	Ca	Mg	K (meq/l)	Na	Cl ⁻		
3.8	45	7.5	0.9	4.4	34	0.85	28

3.5
Table 3.5: Variation in Certain Chemical Properties of Surficial Tailings Materials Collected from the Benson Lake Coast Copper Tailings Impoundment

		<u>Mean</u>	<u>Range</u>	<u>n</u>
Colour		2.5Y4/4	2.5Y3/2-7.5Y4/4	22
E _{Ce}	mmhos/cm	11	2-36	22
pH		3.3	2.5-7.5	22
Total S	%	2	0.6-2.9	22
Max. CaCO ₃ req't	t/1000t	62	18-90	22

3.6
Table 3.6: Relative Proportion of Tailings Area With Varying Degrees of Growth Limiting Factors

<u>Acidity</u>		<u>Salinity</u>		<u>Unoxidized S</u>		<u>Max. CaCO₃ req'd</u>	
		<u>(mmhos/cm)</u>		<u>%</u>		<u>(t/1000t)</u>	
<u>Range</u>	<u>%</u>	<u>Range</u>	<u>%</u>	<u>Range</u>	<u>%</u>	<u>Range</u>	<u>%</u>
1-3	60	<4	22	<1	5	<30	5
3-5	27	4-6	18	1-2	45	30-60	45
5-7	9	6-10	32	2-3	50	60-90	50
>7	4	10-15	0				
		>15	28				

Table 3.7

Variation in Certain Chemical and Physical Properties with Depth
at Selected Sites on the ~~Benson Lake~~ Tailings Pond

Coast Copper

	<u>Depth</u> (cm)	<u>ECe</u> (mmhos/cm)	<u>pH</u>	<u>Total S</u> %	<u>Maximum CaCO₃</u> <u>Requirement</u> (t/1000t)	<u>Colour</u>	<u>Structure</u>
<u>Site 1: Coarse textured tailings with no vegetation</u>							
	0-5	2	3.1	2.7	84	2.5Y3/2	granular granular-cemented
	>5	5	2.7	2.2	68	2.5Y4/4	
<u>Site 2: Medium textured tailings with no vegetation</u>							
	0-5	4	2.8	2.0	62	2.5Y3/2	platy blocky blocky blocky
	5-15	5	2.8	1.5	46	2.5Y4/4	
	15-35	5	2.8	0.9	28	5Y4/4	
	>35	n.a.	6.8	3.4	106	7.5Y4/2	
<u>Site 3: Medium textured tailings with sparse grass cover</u>							
	0-1	7	2.7	1.6	49	2.5Y4/4	platy platy blocky granular
	1-5	9	2.7	2.4	74	2.5Y4/4	
	5-20	4	6.0	3.6	112	7.5Y4/2	
	>20	n.a.	6.1	3.9	121	10Y3/2	
<u>Site 4: Fine textured slimes with dense grass cover</u>							
	0-10	2	7.4	1.9	59	7.5Y5/2	granular granular blocky
	10-20	3	6.7	3.0	93	7.5Y4/4	
	>20	4	6.5	2.3	71	10Y4/2	

Table 3.8: Total Elemental Analysis of Coast Copper Tailing and Background Soils

Depth: Profile 1:	Ca	Mg	Na	K	Fe (%)	Mn	Al	Si	Cu (ppm)	Zn
0-5	6.3	1.8	0.61	0.23	27	0.13	2.7	17	1400	110
5-18	7.6	1.7	0.49	0.15	30	0.14	2.4	15	1100	150
18-33	6.7	1.8	0.58	0.18	31	0.12	2.6	15	700	10
33-53	6.5	1.8	0.58	0.15	30	0.12	2.4	15	800	70
53-83	6.7	1.6	0.49	0.11	36	0.13	2.0	15	800	50
83-100	7.6	3.2	0.60	0.20	18	0.20	3.0	19	1400	130

Background Soil										
F	0.41	0.16	<0.01	0.04	0.9	0.03	0.4	3	1100	50
H	0.51	0.64	<0.01	0.07	3.9	0.04	2.0	8	200	<10
Bfh	0.62	1.71	0.06	0.18	11.3	0.09	6.5	15	<100	70
11 Bfh	0.46	1.38	0.04	0.14	10.7	0.15	6.5	14	<100	20

Table 3.9: Chemical Properties of Coast Copper Tailings

Depth (cm)	Exchangeable					Org Matter (%)	Total N (%)	Available P (ppm)	Total S (%)		
	pH (H ₂ O)	pH (CaCl ₂)	CEC	Ca	Mg (mg/100g)					Na	K
Profile 1:											
0-5	7.2	6.8	4.3	31	0.36	0.03	0.28	1.7	0.03	<0.1	0.28
5-18	7.0	6.6	2.9	51	0.36	0.03	0.38	1.9	0.19	<0.1	0.17
18-33	7.0	6.7	1.5	39	0.47	0.03	0.34	2.8	0.02	<0.1	0.46
33-53	7.4	7.1	1.1	18	0.32	0.02	0.28	2.4	0.21	<0.1	0.86
53-83	7.5	7.0	1.5	23	0.34	0.02	0.27	2.0	<0.01	<0.1	0.86
83-100	7.9	7.4	4.9	23	0.39	0.04	0.65	1.8	0.02	<0.1	0.06
Profile 2:											
0-5	2.7	2.5	9.9	3	0.57	0.04	1.24	0.8	0.020	<0.1	0.32
5-18	7.3	6.9	2.8	33	0.42	0.04	0.53	1.8	0.010	<0.1	2.34
18-33	4.8	4.5	3.5	34	0.38	0.03	0.31	1.8	0.007	<0.1	1.54
33-53	7.3	7.0	1.1	27	0.60	0.03	0.35	2.0	0.003	1.0	0.95
53-83	6.5	6.4	1.4	22	0.30	0.02	0.35	1.4	0.005	<0.1	-
83-100	7.7	7.3	1.6	22	0.37	0.02	0.52	2.3	0.002	<0.1	1.20
100+	7.9	7.4	0.5	17	0.09	0.02	0.22	1.3	0.008	<0.1	0.40
Profile 3:											
0-38	2.8	2.7	3.6	<1	0.27	0.03	0.14	0.8	0.007	0.6	0.46
38-43	3.0	2.8	3.3	<1	0.17	0.03	0.08	1.2	0.004	0.1	0.86
38-43	3.0	2.6	5.1	1	0.32	0.06	0.20	0.3	0.07	0.2	-
43-95	4.3	4.1	2.9	6	0.24	0.04	0.21	1.0	0.003	0.2	0.85
95+	7.4	6.8	0.6	24	0.26	0.03	0.24	2.3	0.002	0.2	1.02
Profile 4:											
0-4	3.2	2.8	4.8	<1	0.09	0.03	0.09	0.8	0.014	0.9	0.29
4-13	3.1	2.8	3.5	<1	0.10	0.03	0.12	1.0	0.005	0.3	-
13-20	3.5	3.2	7.4	11	0.28	0.04	0.20	0.9	0.003	0.2	0.23
20-50	5.3	5.2	4.4	30	0.45	0.03	0.18	2.0	0.001	<0.1	0.46
50-65	7.7	7.2	0.6	23	0.22	0.02	0.26	2.2	<0.001	<0.1	0.40
65-86	7.9	7.4	0.5	19	0.24	0.02	0.23	2.4	<0.001	<0.1	0.23
86+	7.9	7.4	1.0	20	0.24	0.03	0.34	2.0	0.001	<0.1	0.66

Table 3.10: Available Nutrients and Soluble Salts in Coast Copper Tailings

Depth (cm)	Available			Water Soluble Ions			Soil/ Water	
	Ca	Mg (ppm)	K	Ca ⁺⁺	Mg ⁺⁺	Na ⁺ (ppm)	Cl ⁻	SO ₄ ⁼ g/g
<u>Profile 1:</u>								
0-5	10425	80	110	0.91	0.16	0.01	0.03	0.29
5-18	10575	100	131	0.97	0.41	0.01	0.02	0.34
18-33	15825	125	118	0.69	0.32	0.01	0.02	0.29
33-53	14925	120	156	0.75	0.20	0.01	0.01	0.29
53-83	6775	55	95	0.65	0.20	0.01	0.01	0.26
83-100	23625	105	287	1.10	0.15	0.02	<0.01	0.44
<u>Profile 2:</u>								
0-5	400	85	<1	0.15	1.01	0.02	<0.01	4.85
5-18	14075	110	116	0.79	0.21	0.01	0.01	0.29
18-33	6975	105	39	0.60	0.78	0.01	<0.01	0.47
33-53	10175	125	136	0.58	0.27	0.01	0.01	0.26
53-83	7325	65	67	0.55	0.28	<0.01	0.01	0.24
83-100	17375	110	139	0.35	0.09	<0.01	<0.01	0.14
100+	21675	50	54	0.65	0.03	0.01	<0.01	0.24
<u>Profile 3:</u>								
0-38	140	40	3	0.20	0.40	0.02	<0.01	0.49
38-43	85	25	6	0.15	0.30	0.02	<0.01	0.45
38-43	205	50	6	0.49	0.55	0.04	<0.01	0.63
43-95	910	40	49	0.09	0.33	0.01	-	0.81
95+	8375	45	74	0.48	0.14	0.01	0.01	0.19
<u>Profile 4:</u>								
0-4	85	15	5	0.11	0.17	0.01	<0.01	0.51
4-13	50	20	10	0.07	0.18	0.01	<0.01	0.36
13-20	2585	55	13	0.06	0.43	0.02	<0.01	0.82
20-50	8825	125	46	0.52	0.56	0.01	0.01	0.30
50-65	13475	70	107	0.49	0.08	<0.01	0.02	0.18
65-85	17625	95	117	0.48	0.10	0.01	0.02	0.19
85+	14425	70	109	0.56	0.10	0.01	<0.01	0.22

Table 3.11: Available Cu, Zn, Fe and Mn Extracted By 0.1 N HCl

<u>Depth</u> (cm)	<u>Cu</u>	<u>Zn</u>	<u>Fe</u>	<u>Mn</u>
<u>Profile 1:</u>				
0-5	29	2.6	240	44
5-18	94	3.3	1525	34
18-33	0.2	<0.05	<1	32
33-53	0.1	<0.05	<1	40
53-83	38	3.8	1200	54
83-100	3.7	4.4	305	57
<u>Background Soil</u>				
F	419	31	520	200
Bfh1	15	6	370	100
Bfh2	8	4	163	66
II Bfh1	9	4	180	106
II Bfh2	7	1	175	10



Table 3.12 Particle Size Analysis of Coast Copper Tailings

<u>Depth</u> (cm)	<u>Clay</u>	<u>Silt</u> (%)	<u>Sand</u>	<u>Textural</u> <u>Class</u>
1. <u>Cominco Samples</u>				
1.1 <u>Coarse tailing</u>				
1	2	19	78	ls
2	2	14	84	s
1.2 <u>Fine tailing</u>				
1	4	49	47	sil
2	4	38	58	sil
2. <u>Soil Sci. Dept., UBC Samples</u>				
2.1 <u>Profile 1</u>				
0-5	3	77	20	sil
18-33	2	72	26	sil
53-83	1	68	30	sil



Table 3.13: Water Retention Data For Coast Copper Tailings

	<u>Depth</u>		<u>Moisture Content</u>		<u>A.W.S.C</u>
	<u>Tension (bars):</u>		<u>0.1</u>	<u>0.3</u>	
1. <u>Soil Sci. Dept. UBC Samples</u>					
1.1 <u>Profile 1:</u>					
0-15	0.313	0.202	0.057	0.060	0.353
18-33	0.261	0.175	0.047	0.050	0.211
53-83	0.254	0.187	0.047	0.046	0.208

2 Cominco Samples (%)

Coarse	-	5.1	-	1.3	3.8
Fine	-	14.1	-	1.0	13.1

Table 3/4: Bulk and Particle Densities and Saturated Hydraulic Conductivity of Coast Copper Tailings

<u>Depth</u> (cm)	<u>Bulk Density</u> (gm/cc)	<u>Particle Density</u> (gm/cc)	<u>Hydraulic Conductivity</u> (cm/day)
<u>Profile 1:</u>			
0-15	1.58		7.0
<u>Profile 2:</u>			
0-15	1.67	3.36	3.0
55-65	1.81	3.64	2.0
100-110	1.57		4.0
<u>Profile 3:</u>			
0-15	1.68		-
<u>Profile 4:</u>			
0-15	1.61		62
55-60	1.79		4
85-95	2.04		1
<u>Mean</u>	1.72	3.50	

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November 1, 1979

Restoration and Reclamation of Abandoned and
Existing Tailings Areas at Cominco's Con Mine

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Mr. Chairman, Members of the Board:

This evening I wish to discuss progress made to date toward development of a reclamation plan for tailings areas at the Con mine. A detailed report of study results to the end of the 1978 growing season was filed with the Board in December 1978, and, as agreed to by the Board in a letter dated September 27, 1979, a report of progress during the 1979 growing season will be filed with the Board by January 1, 1980.

As directed by the Terms of Reference, our studies have concentrated on reclamation of abandoned tailings outside the Pud Lake tailings area... which we have interpreted to mean the Negus tailings area, a portion of which has been leased to the Con mine, and on reclamation of inactive portions of the Pud Lake tailings area.... which shall be referred to during our discussions as Con tailings.

Basic Types of Investigations

Slide 1: Tailings disposal areas are generally considered non-productive land use areas which are aesthetically displeasing, and if either physically or chemically unstable, are potential sources of air, water and soil contamination.

Slide 2: Revegetation is frequently attempted to stabilize and rehabilitate abandoned tailings. However, a variety of factors can influence establishment and growth of plants on tailings. These factors can include:

- a. the mineralogical, chemical and physical properties of the tailings,
- b. weathering processes and products,
- c. drainage characteristics,
- d. plant specie adaptability and
- e. prevailing climate

Characteristically, factors influencing plant growth on tailings are site specific and can vary within a site and over time.

In studying the potential for using vegetation to stabilize and rehabilitate Negus and Con tailings, we have employed the same approach that we use at other Cominco mines. This involves
Slide 20: implementing five basic types of investigations which are designed to:

1. characterize land adjacent disturbed areas with respect to natural vegetation, potential land use and climate
2. determine the suitability of mine waste, in this case tailings, as growth media for plants. This is usually accomplished by:
 - a. sampling and analysis of tailings for various chemical and physical properties which influence plant life, and
 - b. by growth room investigations which confirm the nature and severity of growth limiting factors.
3. once these growth limiting factors have been identified, we assess various reclamation techniques which have potential for improving tailings for revegetation. Assessment is generally initiated in the growth room and then the more promising techniques are tested on the tailings site in field studies.
4. we also attempt to select plant species which are adapted to prevailing climatic conditions and which possess some tolerance of factors limiting plant life on tailings, and finally,
5. we monitor vegetation growing on tailings for potentially toxic metals.

These are the types of investigations which are in progress at the Con mine and which I will be discussing during the remainder of this presentation.

Natural Landscape, Land Use Capability and Climate

Slide 3: This slide simply illustrates the natural landscape near the tailings areas. Since the Board and the general public present this evening are familiar with the natural landscape and climate in the Yellowknife area and since time is limiting I will not discuss this aspect of our program. I would however, like to make a short comment on the land use capability in the area of the mine and the impact of tailings disposal on alternative land uses.

The physical capability of land for use by agriculture, forestry, recreation and fish and wildlife habitat has been classified based on surveys conducted under the Arctic Land Use Research Program. According to this classification, the land has no potential for either commercial agriculture or forestry under present economic conditions. Organic terrain offers little potential for outdoor recreation use while upland areas, rock outcroppings and shorelines offer moderate potential for outdoor recreation use. While disposal of tailings in Pud Lake and nearby bogs has adversely affected limited areas of fish and wildlife habitat, it would appear that tailings disposal by the Con mine has had minimal adverse impact on other land use alternatives in the region.

As stated earlier I will not review weather conditions except to place on record that weather records have been kept since initiation of the study program through the co-operation of the local Weather Office. I should comment that in developing a tailings revegetation program for the Yellowknife area consideration must be given to the severe winters, the short frost-free period and the semi-arid nature of the region. Limited and unevenly distributed precipitation and relatively high evaporation rates have an

important influence on the revegetation potential of Negus and Con tailings.

Suitability of Tailings As A Growth Medium For Plants

Slide 4: As illustrated in the slide natural revegetation of tailings areas abandoned for many years has been limited to growth of foxtail barley around the trunks of decaying trees partially submerged by tailings.

Slide 5: Detailed sampling and analysis of Negus and Con tailings together with growth room studies confirmed that plant growth on tailings was severely limited by deficiencies of essential plant nutrients nitrogen and phosphorus, and

Slide 6: by the presence of water soluble salts, frequently in concentrations too toxic for germination and seedling growth.

Other tailings properties, including reaction, texture, moisture storage capacity and arsenic content did not appear to limit plant growth significantly.

Before continuing with a review of reclamation techniques for improving tailings for plant growth I would like to comment on the variability in tailings texture and salinity which we have encountered.

Over the extended period of time that tailings were deposited by the Negus and Con mines, changes in milling process, particle size segregation during deposition and removal of coarse sand fractions for mine backfill have resulted in variable tailings texture and salt content, not only among disposal sites but with depth and over the tailings surface.

- Slide 7: This next slide illustrates alternating layers of sand and silt-sized tailings within the profile. While tailings with a high percentage of silt-sized particles have an increased water holding capacity, they also have a higher salt content and reduced hydraulic conductivity relative to coarser textured layers.
- Slide 8: The effect of tailings variability on grass growth is well illustrated in the next slide. While the entire area illustrated in the slide was fertilized and seeded in a similar manner, grass only established on a portion of the site.
- Slide 9: Subsequent sampling with depth indicated that the grass was growing on tailings which were uniformly coarse textured and
- Slide 10: non-saline; while the area with no grass consisted of alternating layers of sand and silt-sized tailings, the latter being found to be very strongly saline.
- Slide 11: Tailings salt content not only varies with texture, but increases during the growing season as moisture migrates upward through the tailings profile and evaporates at the surface resulting in accumulation of high concentrations of salts as illustrated by the white encrustations on the tailings surface.

Cultural Techniques For Improving Tailings as a Plant Growth Medium

Investigations to improve tailings as a plant growth medium have concentrated on the use of fertilizers to provide essential plant nutrients and on revegetation techniques generally used in agriculture to restore productivity to saline soils.

As was illustrated by a slide presented earlier the addition of fertilizer containing nitrogen and phosphorus resulted in excellent grass growth on slightly to moderately saline tailings in the growth room.

Slide 12: Growth room results were subsequently verified by field studies on slightly to moderately saline Negus tailings areas; however,

Slide 13: on strongly saline Con tailings, we were unsuccessful in our initial attempts to establish vegetation by applying fertilizer only.

While on the subject of fertilizer use, I would like to comment on two important trends we have observed on the less saline materials.

Slide 14: First, we have observed that foxtail barley rapidly invaded experimental plots following tillage and fertilizer application. These plant areas generally end up with a dense cover of grass dominated by foxtail barley.

Slide 15: Second, established grass stands including those dominated by
16: foxtail barley deteriorate following discontinuation of maintenance fertilizer applications.

As previously mentioned we were not successful in our initial attempts to establish vegetation on strongly saline tailings by only adding fertilizer. We then conducted a series of growth room studies to assess the effectiveness of organic matter, leaching and salt-tolerant grasses for revegetating the more saline tailing areas.

Slide 17: This slide illustrates the effect of adding varying amounts of peat moss to strongly saline tailings on the growth of salt tolerant tall wheatgrass. Tailings used in the study had a conductivity of 18 mmhos/cm....conductivity greater than 16 mmhos/cm is described as being very strongly saline.

Peat moss was added in amounts equivalent to 0, 22, 44 and 88 mt/ha.

Tall wheatgrass was the only grass specie included in the study to grow satisfactorily on tailings with no peat moss added.

Slide 18: This next slide illustrates the effect of peat moss on the growth of creeping red fescue on strongly saline tailings. Creeping red fescue is less tolerant of salts than tall wheatgrass and growth was not substantially improved until the highest rate of peat was applied.

Slide 19: The next slide illustrates the effect of leaching on the growth of western wheatgrass. Leaching with 1 cm of water per cm depth of tailings reduced tailings conductivity from 18 mmhos/cm to 2 mmhos/cm, a level which has negligible effects on plant growth.

While the tailings used in the growth room were very strongly saline, much higher salt concentrations had been measured in the field. In order to assess these reclamation techniques under field conditions, we established a number of plots on an idle portion of the Pud Lake tailings area.

Slide 20: To assess the effect of organic matter, Peat moss was extracted from a nearby bog and spread on the tailings surface at depths ranging from 0 to 15 cm and then mixed with the surface 15 cm of tailings by rotovating. The sites were seeded to a mixture of grasses having varying degrees of salt tolerance. Fertilizer, supplying the equivalent of 80 kg/ha N, 400 kg/ha P_2O_5 and 50 kg/ha K_2O , was applied at seeding and a maintenance application supplying 45 kg/ha N, 56 kg/ha P_2O_5 and 35 kg/ha K_2O has been broadcast at the start of each growing season.

Slide 21: Peat moss has proven an effective tailings amendment over the short-term, i.e. 3 growing seasons. As might be expected, the effects of peat moss have varied with tailings salinity.

Slide 22: On moderately to strongly saline tailings, salt tolerant tall wheatgrass has sustained growth without peat; however, peat moss

Slide 23: has improved tall wheatgrass growth on these tailings and has

increased survival and growth of less salt tolerant, but more climatically adapted grasses, such as creeping red fescue and meadow foxtail.

Peat moss was applied in this study in amounts equivalent to 0, 88, 132 and 176 mt/ha.

Slide 24: On the more saline tailings, the addition of peat moss was essential for satisfactory growth of tall wheatgrass.

Based on analysis of tailings samples collected at the end of the growing season, it appeared that the large quantities of peat moss added to tailings, limited tailings conductivity increases during the growing season to about one-half of conductivity values measured on tailings with no peat moss.

Peat moss also improves tailings growth potential by increasing moisture and nutrient retention.

Slide 25: The use of water to leach salts from the root zone is also being assessed in the field. The equivalent of 1.2, 0.6 and 0.3 ha-m of water was applied to three plots in 1978 and effectively lowered tailings conductivity from 17 mmhos/cm to 2 mmhos/cm.

Slide 26: First year seedling establishment on leached tailings is illustrated in this slide. Seeding was delayed until July because plots were too wet earlier in the year.

Selection of Suitable Plant Species

Selection of plant species capable of sustaining growth under conditions prevailing on the Con tailings areas is essential for successful revegetation. During the early periods of our study program, we concentrated on assessment of commercially available grass and legume species used in agriculture and reclamation in the colder, semi-arid regions of south-western Canada.

- More recently we have included plant species better adapted to
- Slide 27: northern latitudes and tolerant of saline soils by transplanting
- Slide 28: grasses from saline areas near Fort Smith onto saline tailings at the Con mine.

The native salt tolerant species are of interest because tall wheatgrass, one of the most successful introduced grasses on very strongly saline tailings, has not demonstrated the capability of reproducing from seed at these northern latitudes.

A number of introduced and native grasses have demonstrated satisfactory growth on slightly saline tailings. These include:

- Slide 29: creeping red fescue varieties Boreal and ~~Accepted~~
- Slide 30: meadow foxtail variety Ensign
- Slide 31: Kentucky bluegrass variety Nuggett
- Slide 32: Reed canarygrass
- Slide 33: Red top

As illustrated by the foregoing slides, foxtail barley also grows extremely well on fertilized tailings. All of the grass species shown are capable of producing viable seed when grown in this area.

As tailings salinity increases, the number of grasses capable of sustaining growth decreases to only two species for which seed is available commercially in sufficient quantity for operational ~~scale~~ revegetation. The two species are tall wheatgrass and Lemmon's variety of alkaligrass.

- Slide 34: Several of the native grasses transplanted from the Ft. Smith area have survived and grown satisfactorily.
- Slide 35: The more promising species include Nuttall's alkaligrass, which is illustrated in the slide, desert saltgrass, sloughgrass and reedgrass.

While these species may be better adapted to conditions on the Negus and Con tailings ponds, acquisition of seed in sufficient quantity for operational revegetation is a problem and one which may require more attention of commercially available species prove unsuccessful over the longer term.

Arsenic In Vegetation Growing On Tailings

Monitoring vegetation for metals which may be toxic to animals is an important aspect of any program designed to assess the suitability of tailings as a growth medium for plants. Relative to uncontaminated soil, Negus and, to a lesser extent, Con tailings have elevated levels of arsenic and since initiation of the study program vegetation growing on tailings has been sampled and analyzed for arsenic content. By the end of 1978 in the order of 160 vegetation samples had been analyzed. In 1979, an additional 72 samples were collected and are currently being analyzed.

Briefly summarizing our findings to date, As concentrations in grasses varied widely with tailings area, year sampled and grass specie. Total As in grass forage growing on tailings ranged from a low of 4 ppm to a high of 456 ppm. Grass growing on Negus tailings accumulated As in concentrations 4 to 5 times higher than grasses growing on Con tailings and on soils in the Yellowknife area. The median As value for Negus vegetation was 53 ppm compared to 12 ppm and 10 ppm for Con and Yellowknife vegetation respectively. In the order of 10 ppm is considered normal for plants growing on uncontaminated soils.

It would appear that on idle portions of the Pud Lake tailings area arsenic accumulation by grasses does not present a problem; however, the potential problems, either real or alledged, which can arise from the knowledge that vegetation growing on Negus tailings can accumulate several times higher than background concentrations of arsenic cannot be ignored when considering reclamation alternatives for the Negus tailings area.

Future Studies and Reclamation Plans

Before closing I wish to comment briefly on our plans for further studies and on reclamation of abandoned tailings areas.

Our studies to date have demonstrated that vegetation can be established on Negus and Con tailings and that growth can be sustained, at least over the short term, if maintenance fertilizer is applied annually. Our studies have not been active long enough to enable us to predict if the plant species being used and the treatments being applied will result in a self-sustaining plant community. Over the next few years we plan to monitor developments within revegetated areas on both Negus and Con tailings, being concerned primarily with the capability of plant species to sustain growth, the quality of vegetation being produced and the changes in tailings salinity which may occur over time. The area of saline tailings planted to native salt tolerant plants will be expanded and possibly developed as a potential seed producing area. Currently we have no plans to proceed with operational scale revegetation on abandoned tailings areas. As a matter of fact, the only tailing area which can be considered abandoned is that portion of the Negus tailings which is leased to the Con mine. We recommend against revegetating Negus tailings until alternative land uses, such as industrial land development, have been ruled out. Similarly, reclamation of idle portions of the Pud Lake tailings disposal area should be postponed until the mines requirements for future tailings disposal have been clarified.

That concludes my presentation; if there are any questions I shall be pleased to try and answer them.

Variation in Arsenic Content of Grass Forage

With Sampling Site and Year

	<u>Tailings</u>		<u>Yellowknife</u> <u>Soil</u>
	<u>Negus</u>	<u>Con</u>	
<u>1975</u>			
n:	11	1	1
median:	80	-	-
$\bar{x}$:	89	30	10
range:	30-140	-	-
<u>1976</u>			
n:	40	2	1
median:	46	-	-
$\bar{x}$:	53	20	25
range:	8-193	16-24	-
<u>1977</u>			
n:	17	19	4
median:	49	7	5
$\bar{x}$:	47	10	6
range:	16-86	4-21	4-7
<u>1978</u>			
n:	9	15	5
median:	128	13	11
$\bar{x}$:	175	16	12
range:	40-456	4-32	9-18
<u>1975-78</u>			
n:	77	37	11
median:	53	12	10
$\bar{x}$:	74	14	11
range:	8-456	4-32	4-25

Table 3: The Effect of Varying Degrees of Salinity on Plant Growth

<u>Soil Salinity Classification</u>	<u>Influence on Plant Growth</u>	<u>Electrical Conductivity (mmhos/cm)</u>
Non-saline to very slightly saline	Salinity effects negligible	0-2
Slightly saline	Yields of very sensitive crops may be restricted	2-4
Moderately saline	Yields of many crops restricted	4-8
Strongly saline	Only tolerant crops yield satisfactorily	8-16
Very Strongly saline	Only a few very salt-tolerant crops yield satisfactorily	>16

Source: U.S.D.A. Handbook No. 60, 1954, Diagnosis and Improvement of Saline and Alkali Soils

23

Operational Reclamation Experience at Cominco's Bluebell and Pinchi Lake Mines

1. Introduction

Operational reclamation experience at Cominco's lead-zinc and Pinchi Lake mercury properties will be described. The history of mining, biological setting, land use capability, and the nature and extent of land disturbance will be briefly summarized. The objectives, approach, and method of implementing the reclamation plan including short-term results will be illustrated and discussed in more detail.

2. Bluebell Mine

2.1 Location and History

Bluebell is located within the village of Riondel on the east shore of Kootenay Lake, about 50 km east of Nelson. The property has had a colourful mining history. Over a century ago Indians were reported to have smelted crude musket bullets using ore from the Bluebell outcrop (1). At the turn of the century about 8300 tons of ore were mined and treated in the nearby Pilot Bay mill and smelter. During 1905-1927 about 560,000 tons of ore were mined and shipped to the Trail smelter by barge and railway before Cominco acquired the property (2). From 1952-71 Cominco produced about 4.8 million tons of ore from the Bluebell grading about 5% lead and 6% zinc (3). Ore containing galena and sphalerite was mined by underground methods from sulphide replacements in limestone located under Kootenay Lake.

2.2 Ecological Setting and Land Use Capability

Bluebell is situated on Galena Bay at 560 m elevation. The moderating climatic influence of Kootenay Lake provides more than 150 frost-free days per year and about 2 cm of precipitation per month during the growing season. Total annual precipitation is 90 cm (4). The Riondel area is classified within the Interior Western Hemlock Zone (5). The effect of southern exposure, lakeshore microclimate, and shallow soils developed on glacial till and colluvium from the bedrock outcrop have resulted in forests dominated by Douglas fir with lesser amounts of white pine, larch, cedar, birch, and cottonwood.

Riondel land has best physical capability for outdoor recreation and agriculture according to the Canada Land Inventory (6). Deer winter on south-facing slopes in the area.

2.3 Nature and Extent of Land Disturbance

Total land disturbance at Bluebell was 13 acres and consisted of the industrial site, a waste rock dump, a small tailings spill, and an open pit and mill site remaining from early mining days (Table 1). Tailings were deposited in Galena Bay. Waste rock and tailings consisted primarily of limestone, quartzite, and schist with smaller amounts of pyrrhotite, pyrite, and chalcopyrite.

During 1972-76 equipment and buildings were removed from the property and levelled to concrete foundations. Mine portals were sealed and the open pit and industrial site were fenced.

2.4 Reclamation Plan

Operational reclamation was initiated in November 1977 based on a reclamation plan submitted to the Ministry of Mines and Petroleum Resources.

2.41 Objectives

The objectives of revegetation were to stabilize disturbed land surfaces against erosion, discourage refuse disposal, enhance lakeshore recreation potential, and improve the appearance of the site.

2.42 Approach

Plant species and fertilizer programs were selected for the reclamation plan based on the results of a modest field study program carried out during 1976-77. Characterization of the chemical and physical properties of waste rock and disturbed soils using conventional soil tests indicated that the main plant growth limiting factors were deficiency of organic matter, lack of essential plant nutrients nitrogen and phosphorus, compaction, and moisture deficiency. Species selection trials showed that grasses such as timothy, Canada bluegrass, orchardgrass, and red top established satisfactorily with fall seeding. Spring seeding was necessary for establishment of legumes such as alfalfa, birdsfoot trefoil, and alsike clover. Short term fertilizer experiments showed that incorporation of the equivalent of 56 kg/ha N, 112 kg/ha P_2O_5 , and 56 kg/ha K_2O before seeding resulted in satisfactory establishment of a grass-legume mixture.

2.43 Implementation and Results

Site preparation was carried out by Dorjack Contracting Ltd. of Kaslo B.C. during November 1-9, 1977 using a D8 caterpillar with rippers and a 3 yd³ Caterpillar 950 Pay loader. Waste dump slopes were reduced to 10° slope and graded to blend with the foreshore of Galena Bay. Cemented tailings and, where possible, concrete foundations were buried with at least 45 cm depth of overburden. Metal objects, timber, and garbage were either removed from the site, burned or buried with overburden or waste rock. Cables, barrels, etc. exposed during ripping and re-sloping were removed by cutting torch.

After resloping ammonium phosphate fertilizer was broadcast on waste surfaces at 407 kg/ha using an "Erocon" air applicator. Fertilizer was incorporated to 15-30 cm depth by back-blading with the cat's brush blade or by dragging back the teeth of the payloader bucket. Compact surfaces were scarified in N-S and E-W directions before applying the seed mixture. Creeping red fescue (40%), Canada bluegrass (27%), timothy (26%), and red top (7%) were surface broadcast at 34 kg/ha using Erocon

applicator and cyclone spreaders. Seed was incorporated by payloader bucket leaving contour furrows for trapping moisture on the dump surface. The Payloader pushed down or removed large rocks exposed in ripping and left a tidy surface appearance.

Site preparation was carried out in 7 days (21 md). Seed and fertilizer were applied in one day (27 mh).

In April 1978 Rambler alfalfa (50%) and birdsfoot trefoil (50%) were surface broadcast on all areas at 22 kg/ha using cyclone spreaders. Later in June and September 1978 split maintenance fertilizer applications were broadcast at 224 kg/ha in the form of a complete fertilizer (13-16-10).

About 1800 trees and shrubs were planted in April 1977-78 to screen the open pit and concrete foundations. Bare root 2-0 Douglas fir, ponderosa and lodgepole pine, and paper birch seedlings were supplied by the B.C. Forest Service in Nelson. Arnot bristly locust, a spiny acid-tolerant nitrogen fixing shrub, and black cottonwood were planted to restrict access to the open pit. A local resident donated 28 four year old Eastern maple trees. Trees were planted using pick and-crowbar.

During the initial growing season the grass-legume mixture established and grew satisfactorily on areas having sufficient fines and was dominated by creeping red fescue and timothy.

2.44 Costs

About \$35,000 has been spent on reclamation related activities at the Bluebell mine. During 1977-78, \$27,000 was spent on planning and implementing operational reclamation (Table 2). Since 1972 \$8,000 has been spent administering the Bluebell permit including preparation and submission of permit applications and renewals, annual progress reports, and a very modest field study program. Costs associated with mine abandonment such as fencing, barricading openings, security, etc. have not been included. Similarly receipts from sale of buildings and equipment were not included.

An additional \$10,000 may be spent at Bluebell before reclamation is completed bringing the total reclamation cost to \$45,000. Based on production between 1952-71, reclamation cost about 0.9¢ ton of ore or 9¢ ton of combined lead-zinc produced. Based on area of disturbance, reclamation will cost about \$3,500/acre.

In spring 1979 maintenance fertilizer will be broadcast on all areas. Additional trees will be planted around the open pit and along the lakeshore. Although future plans for the property are currently undecided; revegetation has made the area compatible with neighbouring residential areas and discouraged refuse disposal on the site.

3. Pinchi Lake Operations

3.1 Location and History

Pinchi Lake Operations is located on the north shore of Pinchi Lake, about 50 km northwest of Fort St. James and 160 km north-east of Prince George. The mine was first operated by Cominco during 1940-44 and produced 53,000 flasks of mercury from 700,000 tons of ore (1 flask = 76 lbs). The mine was re-built in 1968 and produced close to 2½ million tons of ore and 176,000 mercury flasks before shutdown in 1975 (7). Cinnabar ore was mined by open pit and underground methods from the Pinchi limestone outcrop and treated in a concentrator and roaster (7).

3.2 Ecological Setting and Land Use Capability

The mine is situated within the Sub-Boreal Spruce Zone at an elevation of 716-814 m (5). The climate is characterized by cold winters and a short growing season. Annual precipitation averages 46 cm with 2.5-5 cm per month during the growing season (4). Forests on the Pinchi outcrop are dominated by lodgepole pine, trembling aspen, and white spruce with scattered black spruce, Douglas fir, cottonwood, birch, and alder trees. Soil parent materials vary from fine-textured glaciolacustrine silts near the lakeshore to shallow coarse-textured glacial till and colluvium at higher elevations (8).

The Pinchi Lake area was reported to have moderately high outdoor recreation capability near the lakeshore and was an important winter range for moose (9). Forest capability on the Pinchi outcrop was low.

3.3 Nature and Extent of Land Disturbance

The total land disturbance at Pinchi Operations is 200 acres consisting of about 34 acres of open pits and waste rock dumps, a 60 acre tailings disposal area, and 106 acres of other disturbances such as roads, the industrial site, lagoons, portals, etc. (Table 3). Twenty five percent of the disturbance consists of tailings, 25% of waste rock, and about 50% of disturbed soils.

During mine shutdown, hazardous chemicals were removed from the property, mine portals were blocked, the West Zone Pit was fenced, the tailings dyke was raised, and a spillway was constructed to control drainage overflow from the tailings pond. A watchman-caretaker currently resides at the site.

3.4 Reclamation Plan

3.4.1 Objectives

The objectives of revegetation were to improve plant growth conditions on disturbed mined-land to encourage succession of self-sustaining native and naturalized plant communities. An initial vegetative cover of suitable adapted grasses and legumes, established using commercial fertilizer, would rapidly stabilize waste surfaces against erosion and improve the appearance of the site.

3.42 Approach

The revegetation approach was based on laboratory, growth room, and field research studies conducted since 1970 in accordance with the surface work permit. Pertinent results will be briefly summarized.

Disturbed soils and parent materials revegetated naturally within 2-5 years following disturbance. However, waste rock and tailings required application of essential plant nutrients nitrogen and phosphorus for establishment and growth of both native and commercial species. Native species invasion and survival and growth of planted conifers and seeded grasses and legumes was poor on unfertilized waste rock and tailings.

Rambler alfalfa, alsike clover, Canada bluegrass, creeping red fescue, timothy, hard fescue, and crested wheatgrass established and grew satisfactorily on waste rock and tailings and produced seed during 7 growing seasons of evaluation. Grasses and legumes were established by broadcast application of seed and fertilizer with no site preparation. Legumes and legume-grass mixtures have provided satisfactory vegetative cover, biomass, and seed production for 4 growing seasons since discontinuation of maintenance fertilizer applications.

During the first few growing seasons invasion of dense legume-grass cover by native plants was limited by competition. Eventually as cover decreased, invasion of native plants accelerated.

The mercury content of grasses and legumes grown on waste rock and tailings was slightly elevated compared to values reported for the same species grown on normal soils; but was lower than values for vegetation growing in the vicinity of mercury mineralization in B.C. (10, 11).

3.43 Implementation and Results

Reclamation at Pinchi has been on-going for a number of years. In 1971 roadcuts, a borrow pit, and portal entrances totalling 15 acres were hydroseeded. Mulch, ammonium nitrate-phosphate fertilizer (24-24-0), and a seed mixture were broadcast at 1120, 233 and 84 kg/ha respectively. In 1973 the 4 acre West Zone Pit waste dump was revegetated using hand-operated cyclone spreaders. Before seeding ammonium phosphate, ammonium nitrate, and muriate of potash fertilizer were surface broadcast to supply 56 kg/ha N, 112 kg/ha P₂O₅, and 56 kg/ha K₂O. The seed mixture was surface broadcast at 112 kg/ha. Maintenance fertilizer applications of 466 and 233 kg/ha applied as 24-0-0 were surface broadcast in 1974 and 1975 respectively.

In May 1978, 76 acres consisting of the tailings disposal area, open pits, waste rock dumps, and areas not likely to be disturbed during removal of surface structures were revegetated.

using Jet Ranger helicopter. Saturated tailings conditions in spring limited access of conventional seeding equipment.

Materials were broadcast on waste surfaces without site preparation. A complete fertilizer (13-16-10) was broadcast on waste rock and tailings at 431 and 862 kg/ha respectively. A Rambler alfalfa (30%), alsike clover (20%), creeping red fescue (25%), red top (10%), and Canada bluegrass (15%) mixture was broadcast at 56 kg/ha.

Twenty-five tons of fertilizer and 2.2 tons of seed were applied by helicopter in 7 hours; 1.6 hours were required to fly the helicopter to and from Prince George. Fertilizer and seed were applied as follows:

- a) at the staging area a 4 man crew loaded 700 lbs of fertilizer or 300 lbs of seed in 30 seconds into two 45 gallon barrels attached to each side of the helicopter,
- b) a fifth person lined up the flight path of the helicopter to control material application,
- c) application rates were controlled by the helicopter engineer by sliding a metal plate to vary the size of opening on the bottom of each barrel and by varying altitude and speed. At 200 feet altitude and 25 mph, materials covered a 25 foot wide strip,
- d) the total time required to load, fly to the site, apply materials, and return to the staging area varied from 4½ to 5 minutes,
- e) the staging area was generally about ½ mile from the point of materials application.

Seed and fertilizer application were uneven in some areas. To improve coverage on these areas, cyclone spreaders were used. This will be remedied in future by using 2 people to align the helicopter and by using proper cyclone applicators mounted on the helicopters.

By late October 1978 waste rock and tailings were covered with relatively uniform seedling populations. Seedlings did not establish satisfactorily on waste rock left at the natural angle of repose or where seed and fertilizer application were uneven. Fertilizer accelerated regeneration of native conifer and deciduous seedlings on waste rock. On tailings invasion of native Nuttall's alkaligrass was promoted by fertilizer. Establishment of seeded creeping red fescue and red top was satisfactory on portions of the tailings pond; but legume establishment was poor and confined to cracks. Relatively poor establishment of seeded species on tailings was attributed to a drier than normal summer.

3.44 Costs

About \$108,000 has been spend on reclamation related activities at Pinchi Operations since 1970. The major cost of \$69,000 was spent on the research program and administering the surface work permit. The balance of \$39,000 was spent on operational reclamation. Of this, \$31,000 was spend on planning and implementing reclamation operations in 1978. (Table 2).

Reclamation cost \$408/acre in 1978 and was similar to costs for revegetating the two smaller areas in 1971 and 1973. Based on production between 1968-75, reclamation cost about 4.3¢/ton of ore and 61¢ per flask of mercury. Including research and administration, reclamation costs to date for areas requiring no site preparation totalled \$540/acre.

About 65% of the land disturbance at Pinchi has been revegetated to date. In 1979 maintenance fertilizer will be applied by helicopter to areas seeded in 1978 and dismantling and removal of surface structures will begin. Current plans are for site clean-up to be completed during 1980. The remaining 38 acres of disturbed land will be prepared for seeding in spring 1981. If necessary an additional maintenance fertilizer application will be made to 1978 areas. Assuming satisfactory establishment on areas planned for seeding in 1981 and the need for only one maintenance fertilizer application, planned reclamation activities could be completed as early as 1982.

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Table 1: Nature and Extent of Land Disturbance and Reclamation
Bluebell Operations

<u>Nature of Disturbance</u>	<u>Area of Disturbance</u> (acres)
Galena Bay waste rock dump	5.0
Open pit waste rock dump	1.0
Mill tailings pile	0.2
Cemented tailings	0.2
Old mill site	0.6
Service and storage area	<u>6.0</u>
	13.0

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CANMET'S TAILINGS' MANAGEMENT STUDY

A JOINT PROJECT OF MONENCO LIMITED,
NORANDA MINES LIMITED, COMINCO LIMITED AND
INCO LIMITED.

THE REVEGETATION PROGRAM
ON
INCO LIMITED'S TAILINGS AREAS

December 1983

T. H. Peters
Agricultural Department
Inco Limited

INDEX

1. The Revegetation Program on Inco Limited Tailings Areas
2. Basic Steps in Inco Limited's Revegetation Program.
3. Inco Limited's Suggested Tailings Research Areas Related to Revegetation.

THE REVEGETATION PROGRAM ON INCO LIMITED

TAILING'S AREAS

There are three areas in Canada where Inco Limited carries on integrated mining and concentrating operations. They are located at Sudbury and Shebandowan in Ontario and at Thompson, Manitoba. The ore milled at all sites is a sulphide ore and consequently the tailings areas have varying degrees of acid generating potential which must be considered in developing successful revegetation programs.

Preliminary test work has been carried out at both Thompson and Shebandowan to develop revegetation programs. However, since major areas at these sites are still operational, no large scale reclamation program has taken place.

The main revegetation program has taken place at the Copper Cliff Tailings Area where approximately 600 hectares have been revegetated in the last 30 years.

The steps in developing a successful vegetative cover on tailings' areas follow a logical order,. Although the main steps are constant, the ability to adapt minor variations into each step is required due to the infinite number of variables which can occur at each site. The principle steps followed at Inco Limited are as follows:-

1. Pre-Seeding Investigation

If possible, this should be done during the growing season prior to the year the area is to be seeded. This permits sufficient time for changes in contours of the area to be made, if required. Samples of the tailings in the area are taken for greenhouse growth tests to ascertain the rates of limestone and fertilizer applications required to ensure successful establishment of the vegetation. In all cases, it is assumed in developing these tests that there is no available plant nutrients present.

This information provides a realistic basis for ordering supplies and establishing costs for budgeting purposes.

2. Site Preparation

Site preparations falls into two categories, the inside beach area and the outside slopes.

The angles of the outside slope will determine the type of equipment to be used in the seeding operation. If the slope is sufficiently gentle that conventional agriculture machinery can be used, the procedure is similar to the one employed in seeding the beach areas. The "step in SPACE" associated with the procedure used to construct the dams in 10' lifts at Inco Limited permits grading of the slopes from their original angle of repose to an angle which will permit the safe use of required agricultural equipment. Slopes facing the south and southwest are usually covered with clay in order that there will be a sufficient quantity of moisture available to permit plant growth during the hot dry periods of the year. Due to the difference in water absorption of tailings and clay, it has been found that the whole slope should be covered with clay to preserve the integrity of the dam. If the top portion is covered and the bottom portion left as tailings, severe erosion will occur in the lower levels as the clay on the upper level sheds the precipitation in heavy periods of rain or snow melt.

Wherever possible, equipment should travel across the slope and not up and down as this practice will reduce the rill and washouts from precipitation until the vegetation is sufficiently established to eliminate this development. In addition when slopes are seeded at Inco, a water permeable chemical sealant is now applied to reduce the development of water runs on slopes.

After slopes have been seeded by conventional agricultural equipment, a mulch is applied with a hydroseeder. In the case of steep

slopes, the mulch is applied with the grass seed and fertilizer by the hydroseeder. This mulch provides shade and reduces moisture loss, thus increasing the survival rate of the young seedlings.

Gradual slopes and the beach areas receive similar site preparation. Approximately half the amount of limestone required to adjust the pH to a satisfactory level is broadcast over the area at least six weeks prior to seeding time. Depending on the friability of the tailings surface, the lime is disced or harrowed into the tailings.

3. Seeding

In the Sudbury area, experience gained over the past 30 years, indicates a late summer seeding provides the optimum chance for seedling survival and successful establishments of grass stands. Seeding now commences after the first substantial rainfall after July 20 each year.

The necessity of having a firm seed bed, to ensure success, will determine whether the tailings are disced or harrowed to incorporate the second half of the required limestone application.

After the limestone is incorporated into the tailings surface 450 kg/ha of 5-20-20 fertilizer (5% nitrogen, 20% phosphate, 20% potash) are broadcast over the area and harrowed into the top 5-8 cm of the surface. A conventional farm seed drill follows seeding 94 kg/ha of fall rye, 22 kg/ha of grass seed mixture and an additional 390 kg/ha of 5-20-20 fertilizer. Prior to 1983 9-11 kg/ha of Brome grass seed was then broadcast after the seed drill planted the fall rye and one half the grass seed, but this step is now omitted. A Brillon seeder is used to plant an additional 22 kg/ha of the grass seed mixture. This mixture compacts the soil and places the grass seed at the proper depth to ensure the maximum chance of germination.

The grass seed mixture currently used is:-

- 25% Canada Blue grass (Poa compressa L)
- 25% Red Top (Agrostis gigantea Roth)

- 15% Timothy (Phleum pratense L)
- 15% Park Kentucky Blue Grass (Poa pratensis L)
- 10% Tall Fescue (Festuca arundenaceae Schreb)
- 10% Creeping Red Fescue (Festuca rubra L)

On slopes, which are too steep to permit the use of conventional farm equipment to seed, a hydroseeder is used.

The seed mixture, the fertilizer and a mulch (Verdyol - trade name) are mixed in the tank with water at the appropriate rates for the capacity of the machine and sprayed as a slurry on the area to be seeded.

In cases where slopes can be seeded with conventional farm machinery, a mulch is subsequently sprayed over the area and in some case a suitable chemical sealant is applied. This treatment reduces water loss from evaporation and erosion runs during runoff from rainfall before sufficient root structure is established by the young plants.

4. Post Emergent Handling

Two to three weeks after the seed has germinated, a light application of nitrogen is applied to encourage growth. Due to the lack of organic matter in tailings, very little reserve nitrogen is available or retained by tailings from the original application.

Harvesting of the rye in the following year is done in such a manner as to leave the maximum height of stubble. This stubble provides shade and reduces surface winds during the growing season. In the following winter it will trap snow, which will ensure adequate moisture for the start of growth the following growing season.

5. Introduction of Legumes

The practice of late summer seedings has made it difficult to establish legumes. The seeds germinate and grow in the fall but do not develop a sufficiently strong and extensive root system to withstand the alternate freezing and thawing and resultant heaving of the surface ground the following spring. Various methods to establish legumes the following year have been tried. At present the use of a power-till seeder is the most promising but dormant fall seedings and seedings just after the snow melt in the spring have shown limited success.

6. Trees

Establishment of grass has been found to be the first step in the rebuilding of an ecosystem. Once ground shade and soil fertility were provided, the natural invasion of trees, principally birch, commenced. Some of these trees are now 3 - 5 m high.

Experimental plantings of more desirable species, with the prospect of future commercial use, are showing success. Jack Pine, Red Pine and hybrid poplar are currently under test.

7. Wildlife Management Area

The possible end use of Inco Limited's tailings as a wildlife management area is being investigated.

BASIC STEPS IN INCO LIMITED'S REVEGETATION PROGRAM

1. The seeding should be established on that portion of the area which is closest to the source of the prevailing wind to minimize covering or damaging of young plants by drifting tailings.
2. Half the agricultural limestone required, should be applied at least 6 weeks prior to seeding. This permits sufficient time for the reaction to raise the tailings pH to approximately 4.5 - 5.5. The remaining half is applied just prior to seeding.
3. In the Sudbury area, late summer is the best time to seed grasses. After July 20, rates of success of seed germination and seedling establishment are enhanced due to more suitable temperatures and the increased availability of moisture.
4. Spring seeding the following year of grass seeded areas or dormant fall seeding of legumes is necessary. Legumes are unable to develop sufficiently strong root systems, if planted with grasses in late summer to withstand heaving of the surface the following spring caused by alternate freezing and thawing.
5. The use of a companion crop to provide shade, and reduce winds is beneficial, if not essential.
6. Several applications of nitrogenous fertilizer should be applied, as required during the establishment period, to ensure maximum uptake and subsequent growth.

7. Slopes, particularly with south and southwesterly exposures should be mulched to provide shade for seedlings and to reduce evaporation of moisture from the soil during the critical period of seedling establishment.

TAILINGS REVEGETATION RESEARCH

1. Establishment of criteria to evaluate the potential of success of permanent vegetation stands.
2. Establishment of criteria to establish the actual benefit of permanent revegetation related to seepage control, etc.
3. Establishment of meaningful chemical analysis of nutrient requirements, e.g., proper management of phosphate supply relative to aluminum and iron ion availability and concentration.
4. Development of procedures to speed up nutrient recycling and decomposition of the thatch by incorporation and multiplication of soil flora and fauna into revegetated tailings areas.
5. Optimum final contour of tailings areas for successful revegetation.
6. Intercept procedures for upward movement of acids and salts in sulphide tailings.
7. Selection of suitable vegetation species.
8. Develop chemical analytical procedures to ascertain acid generation potential of pyrites in sulphide ores and in coal to permit proper amelioration procedures.
9. The effect of residual trace elements (heavy metals on root growth).

10. The adaptability of various hybrid tree species to tailings areas with the ultimate objective of producing a quick maturing harvestable crop of pulpwood, firewood or other forest by-products.
11. Fertilizer or nutrient supply studies to provide a long term nutrient supply for forest species growing on tailings.
12. The influence of an iron pan and the physical structure and texture of tailings on the selection of suitable revegetation species of grasses, legumes, shrubs and trees.
13. The possible effect on wildlife by the uptake of heavy metals from the tailings strata into plants and the subsequent food chain.

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REHABILITATION ACTIVITIES AT NORANDA GROUP MINES

B. Brooks, Horne Division

Introduction

Of all the operations associated with modern mining the impoundment of liquid and solid wastes or tailings disposal has the most profound affect on the environment. The probable major impacts involved with tailings deposition are: aesthetics, fugitive dust, surface water hydrology - its quality and use, ground water hydrology - its quality and use, aquatic ecology, terrestrial ecology, land use, topography and public safety. Just as tailings areas are heterogeneous in their composition so are they diverse in their effects on nature. Some tailing dams only affect the aesthetics of the local area while others affect areas beyond their boundries.

Across Canada Noranda Mines Limited(8) has a total of 10,790 acres of active and inactive disposal areas of which 84 per cent contain some percentage of sulphide, mostly pyrite. The areas containing sulphides can be divided equally into those which should provide little problem to direct vegetation procedures and those with a sufficiently high sulphur concent which will require either the addition of a pH modifier or a top cover or both before reclamation can be fruitful.

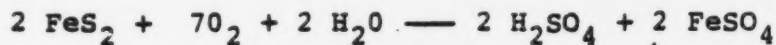
Approximately 92 per cent of successful revegetation of sulphide disposal areas by Noranda has been completed by the Group's Horne Division. Situated in North Western Quebec, the division is renowned for its expertise in the mining and smelting of copper sulphide ore. During its 60 years of operation over 700 acres of land have been used in order to deposite its sulphide waste. Over

the years, the oxidation of the iron sulphide minerals contained in the mine wastes has resulted in the generation of an acidic effluent.

It should be noted at this time that water quality of the effluent being discharged from the active areas is controlled by lime addition and that remedial action is either in the planning stage or being acted upon for the rest of the areas.

Sulphide Tailing Chemistry

The chemistry of acid generation has been well documented⁽¹⁾. The sulphide mineral reacts with air and water to form a sulfuric acid and ferrous sulphate.



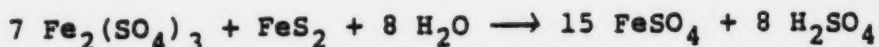
This reaction occurs ordinarily at temperatures up to 11^o C. At temperatures higher than this the ferrous sulphate oxidizes to the ferric state.



The ferric sulphate will in turn hydrolyze to form acid plus an hydroxide. The white material forming on a sulphide dam during the hot summer days is ferric sulphate.



The ferric sulphate also reacts with the pyrite to produce additional acid.



Although the above reactions are an oversimplification of a very complex acid formation process, it does demonstrate the need for air (O_2) and water (H_2O) to proceed. The reactions are also very dependent upon different catalytic agents acting either independently or in combination. The catalytic agents can be physical (temperature), bacterial (*Ferrobacillus* sp. and *Thiobacillus* sp.) and chemical.

All the above reactions have dealt with pyrite (FeS_2) as very little work has been done on the more volatile iron sulphide, pyrrhotite ($\text{Fe}_N\text{S}_{N+1}$). The more rapid oxidation rate of pyrrhotite however can be expected to have an important consequence in the development of tailings acidity.

Work undertaken by the Mineral Research Laboratory, Ontario Ministry of Natural Resources⁽²⁾ indicated that the Horne Division's No. 3 tailings could be broadly described as pyrrhotitic in nature while those from the Waite-Amulet were more pyritic in type. The Waite-Amulet Mining Company operated the second largest mining operation in the region. This copper and zinc producer was controlled by Noranda during its years of production and was purchased just prior to its closure in 1962. Since the 1970's the property has been under the care of the Horne Division.

As this section of the task force deals with the revegetation of spoils and tailings the remainder of the paper shall only briefly touch on the Horne's efforts concerning fresh water diversions, acidic effluent impoundment, etc. It should be noted at this time that it is the Horne

Division's belief that revegetation is only a part, although an important part, of an overall water quality program.

At the Horne Division efforts to delineate and find solutions to the problems posed by acid-generating tailings disposal areas commenced in the late 1960's by the establishment of sampling stations for the major effluent flows and natural watercourses in the area. As analytical data were collected it became apparent that the Division knew very little about the activity of its tailings dams and their effect on the various watercourses.

Acidic effluent from the various dams were seeping into numerous small streams and seemed to be flowing to all points of the compass. These were all diverted away from fresh water streams when possible. The seepage initially clear and colourless, assumes a faint yellow tint which as it is affected by time and atmosphere changes to a deep amber-red. This latter colour is due to the suspended particles of ferric oxide, $\text{Fe}_2\text{O}_3 \cdot n\text{H}_2\text{O}$.

Apart from the environmental impact caused by acidic seepage, the fine granular nature of some tailings material will cause it to be picked up by the wind on occasion to form dust storms. The two dams are located adjacent to the City of Noranda. Surface oxidation gave a yellow-brown appearance to the dams while the surroundings showed decaying trees due to the acidic effluents around them.

Mine Waste Stabilization

There are several known methods (physical, chemical and vegetative and combinations thereof) to stabilize the mineral waste to reduce water contamination and prevent air pollution.

Many materials have been tried for physical stabilization. Covering the dam with bark or smelter slag, harrowing of straw into the top few inches of tailings and the placement of wind-breaks are just a few. Physical methods will temporarily solve the dust problem but will not improve the aesthetics or the water quality.

Chemical stabilization involves reacting a chemical with the waste to form an air and water resistant crust or layer. Again this is only a temporary solution to one of the problem areas. Due to the uneven surface of the disposal area there will be enough irregular overhanging material to allow the high winds to rip out sections of the chemical seal. After two years between 25 to 30 per cent of the seal will have blown away.

The preferred method of stabilization of mineral waste is a vegetative cover.

Noranda's Reclamation Concept

During the past decade from research, trial and error, and common sense the Horne Division has developed a concept quite unique in the field of the reclamation of sulphide tailings areas. The concept involves the use of bioassays to assess the vegetation potential of the wastes to sustain a directly seeded, maintenance free plant cover. That is a vegetative cover directly seeded into the sulfide waste without an overburden cover and that requires no maintenance or care after the initial germination. The bioassay technique took preference over standard soil chemical analysis which following a two year university investigation proved unsuitable as a method for developing a reliable field reclamation program. An assessment of a tailings area using the bioassay technique will reveal any wide spread differences within and between sites in agricultural limestone requirements necessary for sustained plant growth to occur. It will also indicate areas where some sort of overburden should be considered because of cost considerations.

It was Noranda's opinion and those of the specialists of the dam that vegetation would best control the three problems; acidic seepage, fugitive dust and unpleasing appearance of the area. In 1969, Noranda decided to revegetate the Waite-Amulet tailings disposal areas. A contract was entered into with a reclamation company which had a successful record in the tailings field. So sure was the contractor of the state of the art at that time that he gave the Horne Division a written guarantee. It should be noted at this time, that both companies' reclamation experience on acidic sulphide tailings where the surface pH levels varied from 2.8 to 3.5 was very limited. The results bore this out.

Using the technology that had proven successful for him on the tailings areas of Timmins and the Sudbury basin, the contractor disced, fertilized and seeded the entire Waite-Amulet primary tailings dam, a total of 100 acres. On the swampy secondary dam the amendments were just broadcasted. The amendment material rates used were:

- 5 tons of hydrated lime
- 650 pounds of 10-10-10 fertilizer
- 256 pounds per acre of a seed mixture of equal proportions of perennial rye and New Zealand fescue.

Within a month, the large dam was green but during the second month it returned to its original reddish and yellowish brown colors. The initial seeding was virtually a complete failure.

The contractor returned in August of the following year to fulfill the guarantee clause in his contract. Three one acre test plots were set up. It was his belief that the lime rates were the reason for the extremely poor results. The lime rates tested were 5, 7, and 10 tons per acre of hydrated lime. The fertilizer, seed mixture and application rates were the same as the previous year. All the test plots germinated and he concluded that the tailings area required 7 tons per acre of hydrated lime. During October of that year, the contractor spread and disced to a depth of 8 inches, 7 tons of lime per acre. In May 1971, the contractor once again seeded and fertilized the large Waite-Amulet dam. The results were just as disastrous as before.

Initial Noranda Test Program

Noranda made two decisions at this time: first, to release the contractor from his guarantee clause and second, to initiate its own program of reclamation of tailings dam. During the winter, a study was conducted, using a rolling bottle test similar to a laboratory cyanidation test, to determine the amount of limestone required to maintain the pH to a point estimated adequate to sustain growth. The test showed that 25 tons of lime would be required. Using this information, advice from various universities, government agencies, other mining companies, the contractor, and a little common sense, Noranda designed its 1972 test program.

Attempts to establish a vegetative cover over the whole area had been a failure and would not be attempted again until better techniques had been established. The 1972 test program covered only 2.5 acres which was sub-divided into 10 one-quarter acre plots.

TABLE 1
1972 TEST PROGRAM

PLOT NO	LIME TONS/ACRE	FERTILIZER 5-20-20	(LBS/ACRE) 0-46-0	SEED - (LBS/ACRE)	
				MIXTURE	NURSE CROP
1 IRRIGATED	50	1200		80	
2 CONTROL	50	1200		80	
3	50	1200		60	100(CHARLOTTETON BARLEY)
4	50	1200	2000	60	100(CHARLOTTETON BARLEY)
5	50	1200		60	100(OATS)
6	50	1200	2000	60	100(OATS)
7	50	1000		80	
8	50	1000		80	
9	50	3000		80	
10	75	3000		80	

THE SEED ~~MIXTURE~~ WAS EQUAL PROPORTIONS OF:
BIRDSFOOT TREFOIL, CANADA BLUE GRASS, TIMOTHY, RED TOP,
CREEPING RED FESCUE.

Besides varying the combinations of limestones, seed mixtures, fertilizer types and rates, one plot was irrigated. The seed mixture used was basically a variation of the mixture Inco had used successfully in Sudbury. One of the blue grasses was dropped and on the contractor's advice, birdsfoot trefoil was substituted. The results were encouraging.

Satisfactory growth was observed on all the plots, although the use of a nurse crop at the Waite-Amulet proved unsuccessful. There was no sign of the birdsfoot trefoil. Three years later, however, the 1972 test plots, which continue to thrive today, maintenance free, were covered with the yellow flower of the trefoil plant. The irrigated plot was superior for the first growing season. In subsequent seasons the difference disappeared. We continued to monitor the plots during 1973 to formulate our ideas.

Noranda had demonstrated that vegetation could be grown on high sulphide tailings by direct seeding but at a high cost. The cost of applying an overburden cover, clay or siliceous gold tailings, was even more prohibitive, three to five times higher than direct seeding. The monitoring of the field trials indicated that variations in the tailings, granular size, chemical composition, moisture retaining capacity, degree of oxidation and subsequent hard-pan formation, caused varied responses to the revegetation techniques employed. The Horne Division lacked sufficient information to answer all its questions and also the agricultural expertise to ensure success of another large scale revegetation program.

Noranda - University of Guelph Program

In April 1974, a 5 year research program was initiated in co-operation with the university of Guelph, one of the foremost agricultural research centres in North America. Under the contract agreement, a more detailed investigation was undertaken of two principal aspects. These were:

- a) To determine the degree of variation within and between high sulphide tailings as it could significantly affect plant growth.
- b) To improve the techniques being used or develop new procedures with the intention of formulating a basically common program for the amelioration of high sulphide tailings. Although the program was to look at the mine and industrial wastes within the Noranda group of companies the first priority of the program would be the tailings areas in the Noranda region.

Between 1972 and 1977 significant effort was spent on tailings analysis in an attempt to relate known vegetation potential to their chemical and physical properties as determined through growth room and field trial experiments. Numerous analyses were performed in the laboratories of Noranda Mines Ltd., the Ontario's Ministry of Natural Resources⁽²⁾, and those of the universities of Guelph, and South Carolina⁽³⁾. Unfortunately none of the analyses

revealed any consistent relationship between the various parameters. Analyses for total and water soluble components, relationships between sulphur and sulphate in non-oxidized and oxidized tailings and for iron, heavy metals and sulphur concentrations and various ratios all proved inconclusive. The large amount of analytical data recorded up to 1977 had not proved beneficial, and as a result traditional forms of metallurgical and soil analyses were discontinued.

While the academic approach proved frustrating, practical experiments in the growth rooms proved useful in determining the vegetation potential of the various areas in a tailings dam. Using the artificial conditions provided by a growth room or chamber, different combinations of neutralizing agents (pH modifiers), fertilizers and individual plants and seed mixtures were studied.

TABLE II

GROWTH OF BIRDSFOOT TREFOIL AND CREEPING RED FESCUE, ON SAMPLE AREAS
FROM WAITE AMULET TAILINGS TREATED WITH VARYING RATES OF
AGRICULTURAL LIMESTONE

GRAMS DRY WEIGHT/POT AFTER 90 DAYS

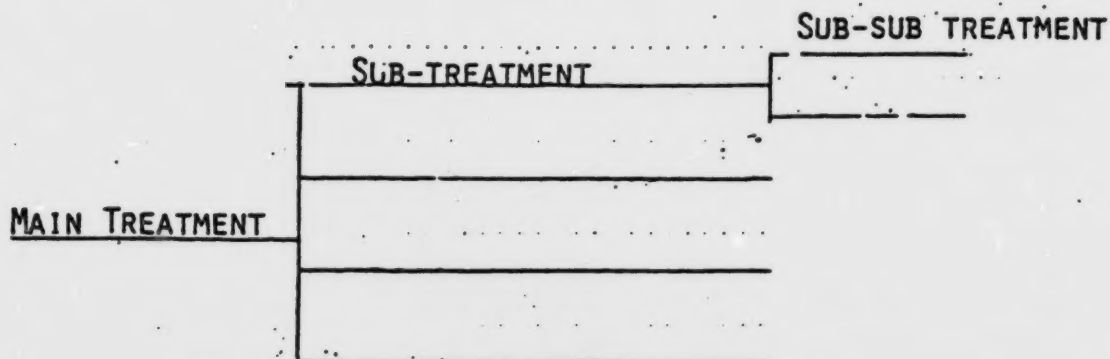
LIMESTONE TONS/AC	SAMPLE AREA & BIRDSFOOT TREFOIL				SAMPLE AREA & RED FESCUE			
	B3	B5	B6	B10	B3	B5	B6	B10
0	0.000	0.207	0.000	0.000	0.000	<u>0.804</u>	0.000	0.031
5	0.041	-	0.000	0.139	0.030	-	0.016	<u>0.268</u>
10	0.019	1.098	0.049	<u>0.748</u>	0.000	1.471	<u>0.329</u>	0.415
20	0.049	1.072	<u>0.295</u>	0.759	0.053	1.535	0.581	0.690
30	<u>0.661</u>	1.360	0.689	0.691	0.075	-	0.676	0.807
40	0.706	-	0.482	0.740	<u>0.745</u>	-	0.523	0.940
50	0.853	-	0.405	0.453	1.184	-	0.375	0.958

— = APPLICATION RATE AT WHICH GROWTH WAS
 CONSIDERED SATISFACTORY.

Results that might require three to four years to obtain in the field were available in four to six months. Although the growth room was operated all year most of the work was scheduled during autumn and winter.

Field trials at the Waite-Amulet recommenced in 1975 based upon the growth room studies. In June, test plots were set up to compare agricultural limestone and rock phosphate as amelioration treatments for acidic sulphide tailings. The experiments were designed as a split-split plot with three replications as shown in Figure 1.

FIGURE 1
1975 SPLIT-SPLIT TEST PLOTS



MAIN TREATMENT: COMPANION CROP

- A. FALL RYE 50 LBS/ACRE
- B. CONTROL

SUB TREATMENT: AMELIORATION MATERIALS

- A. AGRICULTURAL LIMESTONE 25 TONS/ACRE
- B. AGRICULTURAL LIMESTONE 50 TONS/ACRE
- C. AGRICULTURAL LIMESTONE 10 TONS/ACRE PLUS ROCK PHOSPHATE 5 TONS/ACRE
- D. AGRICULTURAL LIMESTONE 10 TONS/ACRE PLUS ROCK PHOSPHATE-10 TONS/ACRE.

SUB-SUB TREATMENT: SEED MIXTURE

A. BIRDSFOOT TREFOIL(EMPIRE)	10 POUNDS/ACRE
.. CREEPING RED FESCUE(PENNLAWN)	20 POUNDS/ACRE
B. CROWN VETCH(CHEMUNG)	20 POUNDS/ACRE
REED CANARY-GRASS(FRONTIER)	10 POUNDS/ACRE

All treatments received an application of 1200 pounds/acre of 5-20-20 fertilizer.

After one complete growing season, the following conclusions were drawn:

1. Seed mixture "A" was superior to mixture "B".
2. The use of a companion crop retards the growth of the legume. This verified the conclusion drawn from the 1972 test plots.
3. Although success was considered adequate with both pH modifiers, on an economic basis agricultural limestone was chosen.

In August of the same year field trials were continued to find a substitute for agricultural limestone, the major cost item of sulphide tailings revegetation. The growth room studies had shown that other materials besides rock phosphate showed promise. The two amendment materials tested were anhydrous ammonia at rates of 500, 1000, 1500 and 2000 pounds per acre and two grain sizes of fly ash, raw and aeroseparated,

at rates of 250 and 500 tons per acre. The materials were allowed to winter before fertilizing and seeding the following June. The pH of the tailings was monitored.

The study showed that although the injection of anhydrous ammonia would instantaneously raise the pH of the acidic tailings from 3.4 to 7.2 and remain at this level for a long time, seeds would not germinate. Fly ash proved to be an excellent amelioration material but the transportation costs for tonnage of this magnitude were prohibitive.

As a consequence of the results obtained from the field trials of 1972, 1975 and 1976, a comprehensive evaluation of the entire Waite-Amulet tailings was undertaken in the growth room using the "bio" assay technique developed by the Noranda-Guelph program. Such a technique had taken preference over chemical analysis which, following a two-year investigation, had proven unsuitable as a method for developing a reliable field reclamation program. Over twenty samples were obtained from the Waite-Amulet for the study. These samples represented a wide range of variations in color, granulometry, location and surface moisture content. The intensive testing confirmed that although a single fertilizer application was suitable for the entire dam, agricultural limestone requirements varied from 10 to 75 tons per acre. Surface plans were developed to indicate the limestone rates to be applied to the various areas of the dam.

Revegetation of the Waite-Amulet Tailings Dam

In addition to developing growth room procedures, the Noranda program had also developed an expertise not normally associated with mining, a curious blending of many disciplines, engineering, mining, agriculture and environment control. All the streams of fresh water were diverted around the tailings areas or in some cases through the discharge area in plastic pipes. Impervious dams were constructed to isolate the effluents affected by the tailings from other water courses in the surrounding region. Detail studies were prepared to determine the drainage patterns in the region and to estimate peak run-off rates. As Noranda's knowledge of the Waite-Amulet area increased so did its awareness of the fact that reclamation of a tailings area was just one important facet of a complete ecological program.

Sufficient confidence in Noranda's ability to apply laboratory results to field situations had been developed by the fall of 1977. The large scale reclamation project envisaged some eight years earlier and abandoned due to failure was reborn. The vagaries of weather during the relatively few frost-free days required a well co-ordinated schedule for the application and incorporation of agricultural limestone, fertilizer and seed. The schedule had to be timed to start when the tailings surface was dry enough to allow large agricultural equipment to operate but before all the surface moisture had evaporated due to the extremes of the summer heat and the tailings texture and colour. Contrary to popular belief, photosynthesis of plants is not continuous while the sun is shining; under the high temperature conditions of summer photosynthesis

may almost completely stop. Furthermore, most accumulations of mill tailings are light in colour and may reflect excessive radiation to the plant surfaces, thus intensifying physiological stress. Inco has measured the under leaf temperature on their tailings areas approaching 140°F. To reduce the risk of failure through abnormal and unpredictable weather conditions the large scale direct vegetation of the Waite-Amulet dam proceeded in two phases; one half of the dam, the windward side, was revegetated in 1978 followed by the remainder in 1979.

The technique used to revegetate the Waite-Amulet dam involved the following procedure:

1. In certain areas where a hardened crust or hard-pan had formed as a result of the oxidation of the tailings, the surface would be ripped or disced depending upon the thickness of the hard-pan.
2. Agricultural limestone was applied using a rotary spreader on a 10-ton capacity wagon.
3. The limestone was incorporated using an 18-foot rotovator which resulted in a well mixed and level seed bed.
4. Next the fertilizer was spread as in the lime application. The Waite-Amulet required a blend of 1500 pounds of 5-20-20 and 500 pounds of 0-46-0 per acre. The filler had been removed to reduce shipping costs.

5. The fertilizer was incorporated using the adjustable teeth of a culti-packer. The machine also compacts the tailings to form a firm seed bed. A harrow was attached to the culti-packer to prepare the seed bed for mechanical seeding; it is not required for hydroseeding.
6. The area was then seeded using:
 - a) A mechanical brillion seeder on areas which were relatively flat and able to retain some surface moisture or
 - b) A hydroseeder on areas which did not retain sufficient moisture and were prone to wind disturbance, or were crested or sloped. A Canadian-made straw and cotton waste mulch, 1400 pounds per acre, was applied on all areas which were hydro-seeded.
7. Two seed mixtures were used:
 - a) For wet, very finely grained areas
30 pounds per acre of tall fescue (K-31)
20 pounds per acre of birdsfoot trefoil, (Empire)
 - b) For relatively dry, coarser grained areas
30 pounds per acre of creeping red fescue (Pennlawn)
20 pounds per acre of birdsfoot trefoil, (Empire)

Six days after seeding the first plants appeared and within three weeks, the areas had a green haze on them. Excellent results have been obtained at the Waite-Amulet dam with an estimated 90 per cent coverage after the initial growing seasons. More than five years have passed since the 1978 seeding and the area continues to support a lush growth up to three feet high which could require no additional care or maintenance.

The smaller secondary tailings dam at the Waite-Amulet property is situated in a low-lying swampy area, completely unsuitable for the heavy farm equipment used on the main dam. It was therefore decided to reclaim this area by the placement of a clay overburden cover over the tailings and surroundings swamps prior to seeding. This work, only feasible during the winter months started in 1978. Up until the end of 1980, only 15 acres had been covered and seeded. In 1981 a major effort was made to cover the remaining area. Contractors were hired and an additional 37 acres were covered and seeded. The acreage would have been greater but for an abnormally wet and warm February which curtailed the project for a month. The cost of this technique is four to five times higher than direct seeding.

All the major fresh water streams running through the swampy tailings area were diverted prior to the placement of the clay. The largest creek was ditched to a new receiving stream almost a mile to the north while a smaller tributary was piped through the area in an 18 inch polyethylene pipe.

Horne Division's No. 3 Dam

The Horne Division's No. 3 dam runs for approximately 5,000 feet down the back of the city of Noranda and covers 130 acres in surface area. Its western and eastern boundaries are two of the three highways supplying access to the city, routes 101, and 117. A total of 11,000,000 tons of mill wastes were discharged in this area from 1931 to 1949. The tailings consist mainly of pyrite and pyrrhotite.

At the same time that large field scale tests based on the Guelph laboratory testwork were being carried out at the Waite-Amulet site similar studies were being conducted at the No. 3 dam. The success of the field trials were identical and developed the same enthusiasm to reclaim the whole dam as they did at the Waite-Amulet.

During 1978 a total of 45 acres were attempted using the same fertilizer and seed rates as were used at the Waite-Amulet. The previous year, the entire dam had been thoroughly sampled. Growth room tests at the university of Guelph delineated the lime requirements for each area. The agricultural limestone was spread at a rate of 25-40 tons per acre depending upon the location.

Unfortunately the success of the Waite-Amulet was not repeated at the Noranda site. The resulting vegetative cover was estimated to be only 50 per cent of what was expected. This figure is somewhat misleading as there are areas where the coverage was as dense as that at the Waite-Amulet and there are other locations where germination did not occur at all.

The inability to take the growth room results and apply them to the total surface area of No. 3 dam when this action had been so successful at the Waite-Amulet raised a lot of questions. A careful examination of the events and conditions encountered during 1978 seeding indicated:

- a) The high water table in the dam made it extremely difficult to operate equipment. This was especially true of the lime spreader.
- b) The Heterogenous nature of the tailings dam was more pronounced than had previously been recognized. Thus in certain locations, the lack of plant growth could be attributed to insufficient limestone.
- c) Climatic conditions -the dam's profile is dish shape. The night after the seeding operation had been completed, a heavier than normal rainfall occurred which washed the mulch and seed towards the center of the dam.
- d) The dish shaped profile of the dam plus the high water table allowed water to pond for several weeks after a heavy precipitation.
- e) The success of the earlier successful field trials could have been due to the fact that the locations chosen had lower water tables than the rest of the dam. In order to give the greatest visual impact to the citizens of Noranda, the field trials were always placed close to the roadways or on the highest ground available.

The result of the study was that the revegetation program scheduled for 1979 was postponed until solutions could be found.

In order to lower the high water table, a small network of sub-surface drainage tiles were installed in July 1980. The trial consisted of 300 feet of a 6 inch collector drainage pipe which intercepted 4,200 feet of smaller 4 inch interceptor drainage pipes. All tubing was covered with a filter sock to prevent the fine tailings material from blocking the perforations in the pipe. The study indicated that although the drainage system worked and it is still operating, the volume of discharge was not sufficient enough to have a significant effect on the water table.

The Chadbourne Mine project's start-up in mid-1979 offered the Horne Division with an alternative method to lower the water table on tailings area No. 3 and to eliminate its dish shape profile. Growth test conducted at the university of Guelph indicated that the Chadbourne tailings require only the Waite-Amulet seed mixture and fertilizer requirements as the material was rich in carbonates. The pH of this overburden material is 7.8 - 8.2. It was the Horne's intention to hydraulically place this material over as large an area of oxidized sulphide tailings as possible to an average depth of 2 - 3 feet.

The deposition program in this area was completed at the end of 1983. Areas which could not be covered by this alkaline siliceous waste due to land elevation or the possibility of destroying large areas of vegetation already thriving is being covered with 18 inches of borrowed clay. The clay will then be reclaimed using standard sod growing methods.

As much fresh water entering the tailings basin as was physically and economically possible was diverted away from the sulphides. The acidic effluent from No. 3 dam which flowed west to the Pelletier drainage system is now pumped to the North Osisko watershed. This will improve the control of the Horne Division's final discharge from their active dams into Lake Pelletier.

Horne Division's No. 1 and No. 2 Dams

For years Noranda's No. 2 dam was seen by tourist and citizens as a blood red pond full of decaying tree stumps. It seems that one's most recent impressions are the ones that last. Although the reasons for the red colour, the oxidized sulphide tailings, have been there since the thirties, the Lake was but ten years old. After children had burnt a trestle between dams No. 1 and 2, the CNR decided to fill in the low area with slag to eliminate the need for a new trestle. The weight of the slag caused the culvert which was to drain the area to collapse. The railway replaced this culvert with a new one but at a much higher elevation and thus formed the red pond.

About this period, the city and the Quebec government decided to build an underpass on the main street of Noranda. The waste from this site was dumped on No. 2 dam and vegetated. For the remaining five years, the image remained a blood red pond, decaying stumps and a 3.3 acre spit land jutting out into the middle of the area, lush with vegetation. The Tree stumps were removed. The availability of the silicious Chadbourne tailings gave the Division an opportunity to change this image. The non-sulphide tailings were pumped into No. 2 dam until the red pond disappeared. During 1981 and 1982 28 of the 32 acre dam was seeded. The results have been quite

successful except for a small 1.5 acre low laying area near the highway and a 1 acre area used in the past by union carbide to deposit the waste from their acetylene plant. These two areas will required a 1 foot overburden cover followed by vegetation.

During 1982 the Division's concentrator completed the covering of the No. 1 dam with 2 feet of the alkaline tailings from the siliceous Chadbourne gold mine. The scheduled reclamation of this area has been delayed for a number of reasons.

- a) Unfortunately a flaw developed in a nearby tailings line used for sulphide waste. Before the line could be replaced almost half of the overburden was covered with sulphides. The area will either have to be recovered with an overburden material or directly seeded after the required amount of agricultural limestone has been applied.
- b) A separate company, Agrinor, has indicated that it wishes to use the area to construct three large greenhouses for plant production. Until the situation has cleared all reclamation plans for this area have been put on hold.
- c) At the time the Division was investigating the area as a site for possible expansion of the slag cooling area.

Horne Division's No. 4 and 5 Dams

The use of the Chadbourne tailings as an overburden is just one part of the Division's water quality program. On our two large dams, 5 miles to the west of the concentrator, a different overburden strategy is being employed. The tailings from the Horne's slag circuit is an inert material consisting mainly of magnetite (Fe_3O_4) and iron silicates. The flotation circuit takes the slag from the Noranda continuous smelter and recovers the copper and precious metals^(4, 5). Growth room tests conducted by the university of Guelph indicated that the material was an extremely poor growth media. The fine size of the material, 80 per cent passing 325 mesh, along with a crusting effect did not allow plant roots, once germinated, to penetrate the material more than a few millimeters. Even though its cementing effect inhibited growth, it also had an advantageous effect in that it also suppressed the infiltration of oxygen, a major component in the formation of an acidic effluent.

The first project to use the inert slag tailings as a barrier to minimize sulphide oxydation was on the 100 acre No. 4 dam. The surface area was covered with 2 feet of the non-sulphide tailings. There are still a few areas, due to higher elevations, which are not covered. These will be completed by a tractor next year. In addition to eliminating further oxydation, the total area will be flooded to create a large lake. During the winter of 1978-80, the retainer dam was raised 10 feet to permit this higher water level. It is well known that water inhibits the infiltration of oxygen. This program will provide a double overburden over the old sulphide tailings, one solid and one liquid. The program has not been fully evaluated as only recently the discharge has stopped flowing from No. 5 dam to No. 4 dam. As previously mentioned this discharge is now pumped eastward to the North Osisko watershed.

On our large 170 acre active dam No. 5, the use of this inert overburden material is also being used. The Division's tailings disposal program anticipates that this dam in future will be used solely for slag tailings disposal. Thus the acid-producing sulphide material will be covered eventually by many feet of inert slag tailings.

Quemont No. 2 Dam.

During 1981, the Horne reactivated an old abandoned sulphide tailings area upon agreement with the Quebec Ministry of Energy and Natural Resources. The dam had been previously used by Quemont Mines Ltd., a division of Kerr Addison Mines Ltd., but it had reverted back to the crown after the mine ceased operating in 1972. The disposal permit covers an area of 250 acres of which approximately 105 acres is exposed sulphide material and 80 acres is a pond averaging 9 feet deep. It is the Division's plan to dispose of all sulphide material in this discharge area. It is an ideal location as there are no other sources of effluent entering the permit site. As in the case with the greatest majority of all sulphide flotation circuits the tailings were discharged into the area at a high pH, 9.0 - 10.5. A monitored alkaline discharge flows to the Kinojevis River which has no difficulty meeting the governmental guidelines. When the sulphide circuit is not operating, as presently due to the world metal market prices, the discharge is maintained by pumping a limed flow into the retention pond.

Although the Horne Division has designated this dam an active discharge area preliminary work has been completed concerning the vegetation potential of the high sulphide waste. Starting in 1971, during the final operating years of the Quemont Mining Company, a series of $\frac{1}{4}$ acre test plots studied the effects of different lime addition rates as well as different seed mixtures. Over the years none of the growth has persisted with the exception of a single plot which was covered with a 10 inch layer of waste rock and then topped with 10 inches of sand before seeding. Each year the vegetation coverage of the overburden plot becomes less and less as dunes of fugitive dust creep over the small area. In 1972 the Quemont Mining Company concluded that an overburden cover would be the most economical method to establish a vegetative cover. During 1979 growth room studies showed that agricultural limestone requirements for the disposal area varied from 25 to 125-plus tons per acre and that there was no truly discernible pattern in the distribution of the limestone requirements. The studies also indicated that fertilizer application levels, especially high levels of phosphate applications, appeared critical for successful plant growth. This is the one factor that has been common in all the Horne's growth room studies and field programs on sulphide tailings. There is a striking response to the level of phosphorous fertilizer application. The same may be true of nitrogen applications but since the cornerstone of the Horne's revegetation program involved the establishment of a legume species, particularly the legume Birdsfoot Trefoil (*Lotus Corniculatus*), only minimal rates were ever used.

The consensus of opinion is that an overburden cover on the Quemont No. 2 dam would be the most practical and economical method of establishing a vegetative cover. The closest location of sufficient suitable overburden material is approximately three miles away. Detailed reclamation plans have not been contemplated for this sulphide dam in the near future as it has been designated an active working dam and proposes no environmental threat from fugitive dust or in the quality of its effluent discharge.

Quemont No. 1 Dam

The Quemont No. 1 dam runs into Lake North Osisko between the Horne Division's plant yard and the Noranda Golf Course. It started as an emergency tailings discharge area as well as a location to receive the Quemont concentrator thickener overflows and the mine water discharge. Later on the tailings were extended further into the lake in an effort to stabilize the ground over an underground working area. The dam extension also allowed the construction of the No. 3 ventilation shaft as it formed a peninsula out into the lake. During the later life of the mine, closed in November, 1971, more sulphide tailings were deposited in the area to "level off the tailings surface". Although all of the above reasons for discharging sulphide tailings into and along the shoreline of a lake seemed valid during the time they were carried-out, in retrospect they were not.

At the same time as vegetation experiments were being carried out on the large No. 2 dam Quemont Mines Ltd. was conducting similar tests on their emergency area, No. 1 dam. Two of the eight test plots were covered with an overburden of clay, rock and sand. One received 7 tons per acre of agricultural limestone while the other received 75 tons per acre. The non-overburden plots received from 50 to 200 tons. The fertilizer applications were either 6400 pounds per acre of 0-20-0 plus 1920 pounds per acre of 5-20-20 or 1920 pounds per acre of 5-15-15. A variety of 10 different legume and grass species were seeded at 88 pounds per acre with and without a 2 bushel per acre rye grain nurse crop. The results were spotty to nil where less than 100 tons per acre of limestone were applied. Unfortunately before any serious evaluation could be made the water level in the lake rose as a result of a beaver dam constructed across the lake's discharge channel. Quemont Mines Ltd. did however conclude that the tendency of the sulphide tailings to form a crust on the surface as well as a hard pan was a serious handicap for plant growth. Their report also concludes that a soil cover or similar overburden cover would be the most economical and possibly the only way to establish a vegetation cover on their No. 1 dam. This is similar to the conclusions drawn for their No. 2 dam. The overburden plots flourished for a number of years until even they were covered by acidic water as a result of a high lake level.

In December 1983, after the Horne Division had completed the covering of its own No. 3 dam with an overburden layer of Chadbourne tailings, the silicious gold tailings pipeline was installed to start the covering of the old Quemont No. 1 dam. It is Noranda's intention to cover the area with several feet of the non-sulphide waste material. The area will then be vegetated using a program similar to the one

designed for the Horne's No. 3 dam. The covering of the sulphide area will take over a year as almost half of the acres to be covered are either under water or on the lakes flood plain.

Quemont No. 3 Dam

This small 20 plus acre discharge area runs adjacent to the Horne's No. 1 dam. It was maintained as a stockpile for a pyrite concentrate which was sold to a number of customers while the Quemont mill operated. When the mine closed there was several hundred thousand tons of concentrate stockpiled with an average sulphur content of 46 per cent. It is believed that this area will have to be isolated from the surrounding environment to minimize the effect it has on the local ecology.

Normetal Mine Ltd.

Located 72 miles north of Noranda, Quebec this copper, zinc, pyrite mine operated from 1935 to 1975. During this period over 11,100,000 tons of sulphide ore were mined which resulted in three large sulphide tailings dams. The tailings dams boarder along the northern edge of the town and the western bank of the Calamity River. During certain weather conditions the sulphide tailings would cover the town with a reddish-brown dust. From 1968 until the closure of the mine

attempts to establish a vegetation procedure for the 40 per cent pyritic tailings were tried yearly with little success. The size of the test plots ranged from small hand raked areas to a large 7 acre plot seeded by a contractor. In the early years the formula tried was low rates of lime and fertilizer additions with high rates of seed.

A brief history of these early attempts follows:

- a) In 1968 two small test plots of unknown dimensions were worked by hand. The results were discouraging and what growth was established died off at an early stage.
- b) In 1969 a contractor was engaged to develop a reclamation program. It was the same contractor who seeded the Waite-Amulet dam. He selected seven acres of slope plus one half an acre of flat surface. Three tons per acre of lime were added followed with 650 pounds per acre of 10-10-10 fertilizer. The seed mixture, perennial ryegrass and New Zealand fescue, was applied at a rate of 265 pounds per acre. It should be noted that one half of the slopes was hydroseeded while the rest of the area was seeded with a seed drill. Very little success was noted on the flat surface while the slopes were written off as a complete failure.
- c) The following year the contractor treated 4.5 acres of flat tailings surface with the same seed and fertilizer applications as the previous year. The lime was increased to 10 tons per acre. On part of the area a mulch of wood chips was spread. Although the results were an improvement over the past years they were far from satisfactory. The area which had the wood chip mulch appeared to have the best growth.

d) In 1971 the contractor returned to re-seed the area again with the addition of 30 tons per acre of limestone but keeping the seed and fertilizer rates the same as the previous year. The resultant vegetation was a significant improvement over previous efforts. Again there was evidence that a wood chip mulch improved the vegetation's success rate. During the same period the contractor was investigating the use of basic asbestos waste. Two trial areas were spread with 40 and 60 tons per acre of asbestos tailings; these were disced into the acidic sulphide waste to a depth of 6-8 inches. The trial plots were treated with the same seed and fertilizer applications as mentioned previously. The results were as negative as similar test plots he installed on the Noranda tailings areas.

e) In 1972 after consultation with the contractor, and Noranda and Quemont personnel Normetal redesigned its program. Lime addition rates of 15, 25 and 30 tons per acre were investigated. The seed mixture was changed to Timothy, K-31, Trefoil, Alsike clover, and crownvetch and the application rate was reduced to 50 pounds per acre plus a barley cover crop. The fertilizer rate was increased to $\frac{1}{2}$ a ton per acre. Although the growth was patchy it was an improvement over the earlier testing. The mine personnel concluded that limestone application rates higher than 30 tons per acre were required.

f) In 1973 8 acres of sulphide tailings were covered with approximately 1600 cu. yards of a sand and clay overburden. The following year the area was successfully seeded. This was the last seeding attempted while the mine was in operation.

In 1980 a five year rehabilitation plan was developed with the assistance of the Group's Environmental Control Co-ordinator and the Horne Division of Noranda Mines. Basically the project entailed the installation of drainage ditches around the parameter of the sulphide disposal area to intercept all fresh water which previously flowed over the waste material creating acid. The extremely high dam walls were regraded to a slope of less than 20 degrees. All of the exposed sulphide tailings were covered with 12 inches of sand from an adjacent borrow area. This sand material was sent to the growth room for "bio assay" tests and for standard soil test analyses. The analyses revealed no highly acidic or high total salt situations. Both pH and total salts were in the normal range of normal agricultural soils. Like the tailings itself the sand was very deficient in phosphorous and potassium. Of the micro-nutrients calcium was considered adequate while magnesium tended to be on the low side.. The "bio assays" indicated no apparent problems with the overburden as the tests produced acceptable growth. The seeding procedure is similar but not identical to what is used on the gold tailing overburden used at the Horne Division. The seed mixture calls for 30 Ibs per acre of Creeping Red Fescue and 20 Ibs per acre of Birdsfoot Trefoil while the ratio for Chadbourne tailings is slightly higher at 40 Ibs of Creeping Red Fescue and 30 Ibs per acre of Birdsfoot Trefoil. The fertilizer, 5-20-20, is applied at 1000 pounds per acre while the Horne used 1500 pounds of 5-20-20 plus 500 pounds of 0-46-0 per acre. Both the Normetal and the Horne apply 2000 pounds per acre of mulch although the type is different. Normetal uses a hallow form wood fibre mulch from Texas. The Horne uses a straw paper cotton mulch from Canada. This is the same type as used by Inco and Ontario Department of Highways. Both the Horne and Normetal use a Brillion grass seeder with a spilt seed box followed by a hydromulcher.

To-date Normetal No. 1 and No. 2 tailings discharge areas have been revegetated. One third of the large No. 3 tailings area has been completed and the remainder of the dam has been covered with the sand overburden. This May it will be seeded. All that will remain to be done is touching up the few areas which were not successfully vegetated, placing a central drainage system in the area between the three dams, and seeding the old plant area.

This will fulfill the commitments of Normetal Mines Ltd. as outlined in their letter of intent which was submitted to and accepted by the Ministre de l'Environnement de la Province de Québec.

Conclusions

Noranda's efforts to establish vegetation on highly acidic mine tailings and swamps have been successful. Even though the research contract with the Crop Science Department of the University of Guelph terminated in 1979, the use of growth rooms will continue for other revegetation projects. A great deal of interest from other mining companies across Canada has been shown in Noranda's revegetation program and research projects have been undertaken on the behalf of several companies outside the Noranda Group.

The ability to establish a maintenance-free vegetative cover on acidic mine tailings by direct seeding has been demonstrated. Where a successful vegetative cover has been achieved natural seeding by indigenous species follows as evidenced by the appearance of many trees on both Waite-Amulet & No. 3 dams. Many of the self-seeding trees stand over 15 feet in height. The fauna as well as the flora have returned to what was once a barren and sterile environment. The birds have returned to nest and the insect population, especially the bees, are flourishing.

It is the Horne Division's opinion that a dense vegetative cover will either solve or will largely reduce the three problem areas previously mentioned.

1. Vegetation appears to have reduced the volume of acid seepage from the dam. The ability of a vegetative cover to reduce acid seepage from mine wastes has been documented in the United States.^{5,6} It is a well known biological fact that vegetation utilizes enormous quantities of water in its life processes. Precipitation

is intercepted and absorbed by the plant roots and is transpired back into the atmosphere thus reducing the amount of water which would percolate through the tailing mass and emanate the seepage. The plant leaves themselves intercept large amounts of precipitation which evaporates into the atmosphere before reaching the acidic tailing surface.

Presently there is insufficient evidence to indicate whether the vegetative cover has had any effect on the water quality. It is probably too soon to tell as the vegetation has not matured in some areas to form any depth of organic layer.

2. Dense vegetation eliminates the problem of fugitive dust clouds emanating from the tailings surface.
3. One would hardly raise an argument by stating that the aesthetics of the area are improved.

The establishment of a vegetative cover also had a further effect. The organic matter resulting from a mature vegetative cover has developed into soil layer. It is the formation of this organic layer that has allowed the indigenous species to propagate.

Noranda's experience at the Waite-Amulet and its other properties has shown that vegetating a sulphide tailings area is just one part, although a crucial one, in an overall ecological program.

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APPENDIX A

Other Active Tailings Areas Within the Group

During the period that the Horne Division was formulating its knowledge of vegetating sulphide waste disposal areas other mines within the group were independently developing their own program. With the exception of Pamour Porcupine Mines Ltd., the Horne Division has not in any way assisted the various programs. The division did however make available the services of its contract with the University of Guelph.

Although visually the number of acres of reclaimed acidic tailings seems small this by no means reflects on the amount of commitment, thought, effort or number of test acres tried. Many of the mines have been back year after year after year over an area in an effort to reclaim it.

a) Brunswick Mining and Smelting Co. Ltd. - Mining Division

To-date all studies of their high sulphide waste disposal areas have been confined to the growth room. "Bio-assay" tests using limestone rates of 0 to 200 tons per acre showed little success. What few plants which germinated at the high amendment levels soon died back. No success at all was recorded on the samples of fresh tailings which had a natural pH of 6.5. The pH of the oxidized waste is in the 2.0 to 3.0 range. Growth room test work to vegetate their waste water treatment plant sludge have proven successful. The management has terminated any test work on their large tailings area as it is anticipated that the area will remain active well into the next century.

Brunswick Mining and Smelting have continued to work on the large area of sub-soil surrounding the tailings area and along thin haulage roads. Last year they hydroseeded a five acre test plot with encouraging success. The seed mixture is made up of tall Fescue, Creeping Red Fescue, Birdsfoot Trefoil, and a Fall Rye nurse crop. The mulch used was Verdyol. They now plan to hydroseed 20 acres per year of sub-soil with a soon to be purchased hydroseeder.

Their large tailings areas and long haulage roads do present a problem of fugitive dust but they have not experimented with chemical sprays to arrest it. They do however use a chemical spray, Alchem 8A08, on the concentrate in the railcars.

b) Heath Steele Mines Ltd.

The mine is situated east of Brunswick Mining and Smelting Co. Ltd. near the city of Newcastle, New Brunswick. The chemistry of the 500 acre sulphide waste disposal area has been well documented⁽¹⁾. The pH of the tailings vary from 1.6 to 2.1. Growth room test work has indicated that the agricultural limestone requirement is from 60 to 80 tons per acre for direct seeding. It has been recommended by Dr. E. Watkin that further research is required on the limestone to fertilizer ratio before a revegetation plan can be formulated for this dam.

c) Mattabi Mines Ltd.

This mine is situated north of the town of Ignace, Ontario. The tailings area is 400 acres. It has been reported (11) that between 40 to 45 per cent of the tailings is siliceous with approximately 95 per cent of the remaining material is pyrite with a small amount of pyrrhotite.

Although Mattabi has never conducted growth room tests on their tailings material they did carry out field test plots in the summers of 1975, 76 and 77. In 1975 24 plots measuring 25 feet by 25 feet were treated with 3 pounds per plot of hydrated lime which was incorporated by hand raking. The next day three different fertilizers were applied to the various plots, 12.5 pounds of 13-9-7, 7.5 pounds of 12-13-7 and 11.5 pounds of 13-7-7. Two days later the plots were seeded. The seed types used consisted of Timothy, Creeping Red Fescue, Red Top, Canada Blue, Alsike Clover, Birdsfoot Trefoil and Crown Vetch. From the above seeds different combinations were planted as well as the Noranda and Mattagami mixtures. Approximately three weeks after seeding three pounds of agricultural limestone was added to each of the plots. Two days later an additional 10 pounds of agricultural limestone per plot was added. Not noticing any change in the sparse vegetation nor any significant increase in the pH of the tailings 16 of the plots were abandoned. The remaining 8 plots were redone in the middle of July. Changes were made in the seed mixture, now 50 per cent Timothy, 25 per cent Red Top, 12.5 per cent Canada Blue and 12.5 per cent Creeping Red Fescue, the amount of agricultural limestone and the amount of fertilizer. At the time of re-seeding each of the 8 plots had received 3 pounds of hydrated lime, 20 pounds of agricultural limestone

and 15 pounds of fertilizer. One week later after noting that the pH of the plots remained at 4 an additional 20 pounds per plot of agricultural limestone was applied. Two weeks later for the same reason an additional 20 pounds of limestone plus 10 pounds of fertilizer were incorporated. All through the testing period the plots were irrigated. Although some grass grew in small patches in the plots the success of the field trials were "limited to a large extent". As well as planting grasses Mattabi planted 20 poplars and 20 willows but the success rate was even more pronounced than the grass test plots.

In 1976 the field trial program consisted of seeding $\frac{1}{2}$ acre of tailings, $\frac{1}{2}$ acre of overburden and $\frac{1}{5}$ acre of stockpile. The tailings plot was sub-divided according to surface moisture content, A = 22 per cent, B = 14 per cent, and C = 6 per cent. In response to low pH readings taken applications of hydrated lime and agricultural limestone were added as shown throughout the test program.

Lime Application on Tailings Plot

Date	Type	Lb	Lb/acre
May 19, 1976	Pulverized limestone	480	1,920
May 25	Pulverized limestone	400	1,600
June 14	High grade lime	200	800
June 18	Pulverized limestone	200	800
June 18	High grade lime	250	1,000
June 23	Pulverized limestone	300	1,200
July 7	Pulverized limestone	3,440	13,760
July 27, 1976	Pulverized limestone	1,680	6,720

On July 8th the plots were seeded at a rate of 400 pounds per acre. The mixture consisted of 20.3 per cent Rye, 27.1 per cent Oats, 4.4 per cent Canada Blue, 20.3 per cent Timothy, 16.0 per cent Creeping Red Fescue and 12 per cent Red Top. The fertilizer was applied twice at a rate of 400 pounds per acre of 10-20-6, once before the area was prepared and then a month after seeding. All through the growth period the area was irrigated. The results of the effort were similar to the previous year. By the end of August most of the grass had died except in section C, which had maintained a sparse growth throughout the year.

The entire $\frac{1}{2}$ acre overburden test plot received 1280 pounds per acre of agricultural limestone and 400 pounds per acre of 10-20-6 fertilizer three weeks prior to seeding. The seeding mixture made up of equal portions of Timothy, Red Top, Canada Blue, Creeping Red Fescue was applied at 300 pounds per acre. Three weeks later Red Clover was spread by hand over the test plot. The field trial was a success although the Red Clover did not respond.

A test program similar to the overburden trail was applied to the stockpile. This stockpile consisted of sand, gravel and clay. No lime was added and the 8-30-4 fertilizer rate was 300 pounds per acre. As was the case with the overburden the trial was a success.

In 1977 an experimental seeding and mulching program was undertaken. A total of 10 acres were mulched. The photo consisted of various soil types and slope gradients found on overburden, retaining dam and tailings.

All areas were hydroseeded using Green Conweb wood fiber on the flat plots and Conweb 2000 fiber on the slopes at a rate of 1,400 pounds per acre. A 17-17-17 fertilizer was applied at a rate of 520 pounds per acre on all plots except one where 100 pounds per acre of 34-0-0 was applied. A seed mixture formulated by Pickseed Ltd. was applied at 100 pounds per acre. The mixture was 10 per cent White Clover, 20 per cent Perennial Rye Grass, 20 per cent Tall Fescue, 15 per cent Creeping Red Fescue, 15 per cent Timothy, 10 per cent Kentucky Blue Grass, and 10 per cent Birdsfoot Trefoil. The fertilizer, mulch, and seed were applied by a hydromulcher. The results were successful on all overburden and dam sites. There was no growth on the tailings plot.

Since 1977 there has been no further field trials at the Mattabi mine site.

d) Noranda Mines Ltd. - Geco Division

The Geco Division is situated near the town of Manitouwadge, Ontario. Field trials on their 31.5 acre sulphide waste disposal area, 20 per cent pyrite and 5 per cent pyrrhotite, started in 1970 using the same contractor as the Horne Division was using at the time. For their test area Geco chose a flat 10 acre site situated near the CNR rail line. Lime was applied at a rate of 5 tons per acre and disced into the top 6 inches of the sulphide tailings. A 10-10-10 fertilizer was applied at a rate of 650 pounds per acre. A seed mixture of equal proportion of Perennial Rye and New Zealand

Fescue was seeded using a Brillion grass seeder and in some areas a hydroseeder. The application rate was 265 pounds per acre. The success of this initial effort was extremely poor.

In 1976 Geco decided to conduct another field trial. This time they hired local equipment and designed the experiment themselves with some consultation. The area chosen for the program was a 10 acre sloping site just above the area seeded in 1970. The 10 acres were covered with 6 inches of local gravel to act as a barrier to the suspected upward capillary action of the acid being generated by the oxidation of the sulphide tailings.* An added side benefit of using the gravel was that it assayed 16 per cent CaO . The gravel layer was topped with a layer of clay and muskeg. The area was then fertilized and seeded. The seed mixture was composed of Yellow Clover, Red Clover, Brome Grass, Alfalfa and Birdsfoot Trefoil. This trial was a success exhibiting a luxurious growth of vegetation. As the dam was an active area all further field trials ceased but the interest in how to vegetate their sulphide dam remained. In the latter part of the Horne Division's Guelph program when it became available to the other members of the Group Geco Division was one of the first to request participation.

A total of 15 representative samples of their sulphide disposal area were sent to the University of Guelph for "bio-assay" testing in their growth room. The pH of the samples was 2.1. Dispite the large variation in age,

* The slopes were graded before application of the gravel, to permit operation of a tractor and seeder. Also, former roadways were graded to allow access.

colour, and particle size all samples exhibited a high growth potential. There was no indications of dieback of individual plants by the end of the growing period. Acceptable to excellent growth of the three plant species tested, Tall Fescue, Creeping Red Fescue and Birdsfoot Trefoil, was obtained on all of the samples except one when treated with 25 tons per acre of agricultural limestone. The one exception, a sample of course freshly poured unoxidized sulphide tailings obtained near one of the first spiggots, required treatment with 50 tons per acre of agricultural limestone before it obtained equivalent growth.

e) Goldstream Division

The newly opened Goldstream division is situated near the city of Revelstoke, British Columbia. Since it is just starting production the vegetation of its sulphide tailings dams is in the distant future but already Noranda Mines has begun to discuss this future.

f) Langmuir Mines Ltd.

Langmuir Mines is situated near the town of South Porcupine, Ontario. Owned jointly between Noranda and Inco it operated during the seventies producing a 112 acre sulphide tailings disposal area. Soon after the mine opened 4.75 acres of borrow material was placed on the dams around the auxillary pond and at the end of the main dam. The contractor hydroseeded 800 pounds per acre of 10-10-8 fertilizer with 25 pounds per acre of Kentucky-31 and 20 pounds per acre of Birdsfoot Trefoil. The results were excellent.

In 1978 Langmuir carried out 9 small in-house lab scale tests. No limestone was applied to the test containers. The 7-7-7 fertilizer rates were 300, 600 and 900 pounds per acre. The seed mixture contained 15 pounds per acre of Tall Fescue and Birdsfoot Trefoil at rates of 15, 25, 30, 60 and 90 pounds per acre. It was recorded that the most encouraging results were on the container which received 600 pounds per acre of fertilizer and a seed mixture consisting of 15 pounds per acre of Birdsfoot Trefoil. The results encouraged Langmuir to request the assistance of the Horne-Guelph revegetation program.

Three samples, one from the emergency spill area and two from the main disposal area were sent to the Guelph growth rooms. The samples were evaluated with four forage species, Birdsfoot Trefoil, Crownvetch, Tall Fescue and Creeping Red Fescue and three fertilizer combinations, 5-20-20 at 1500 pounds per acre, 5-20-20 at 1500 pounds per acre plus 0-46-0 at 500 pounds per acre, and 5-20-20 at 1500 pounds per acre plus 0-46-0 at 1000 pounds per acre. Satisfactory growth of Birdsfoot Trefoil, Tall Fescue and Creeping Red Fescue occurred on the samples from the main disposal area. The growth rate of the crownvetch proved unsatisfactory. No germination of any sort was recorded on the sample from the emergency spill area. It is possible that the sample was of freshly poured tailings which historically have been hard to revegetate prior to oxidation. The fertilizer recommendations were for the use of 1500 pounds per acre of 5-20-20 plus 500 pounds per acre of 0-46-0. The mixture would be Birdsfoot Trefoil with either Tall Fescue or Creeping Red Fescue depending on site conditions. Tall Fescue requires moist conditions for optimum growth while Creeping Red Fescue is better

adapted to drier conditions than those with impeded drainage. So much time has passed and weathering occurred since the above test work has been completed that additional test work would be required to confirm the approach to take.

g) Matagami Division

The mill rejects its tailings into a 300 acre disposal area which used to be Watson Lake. The area also use to receive tailings from the now closed Orchan concentrator. The tailings have an average pyrite and pyrrhotite content of 22 and 18 per cent respectively. Most of the pyrrhotite originated from the Orchan mill.

A revegetation program for mine tailings has been in progress since 1970.

h) Pamour Porcupine Mines Ltd

Almost all of Pamour's 15 tailings disposal areas, 1765 acres, are none reactive silicious gold tailings. Approximately 42 per cent of the tailings areas are inactive of which 16.5 per cent has been reclaimed.

The areas which are considerate reactive or acid producing are:

- a) the small "trap shoot" area on the Delnite property
- b) a small side slope on the Aunor no. 1 dam
- c) the large sulphide tailings disposal area situated behind the old hydro building at the Schumacher Division

At all of the above locations the ph of the waste was in the 2.0 to 2.2 range. They also recorded 3 to 10 times the normal salt assay of the other non-reactive tailings sampled.

Mine

The Schumacher ~~Division~~, formally McIntyre Mines Ltd., has the distinction of completing the earliest reclamation project within the group. The mines first tailings disposal area was the western end of Pearl Lake. They continued to pore their non-reactive gold tailings into this area until this portion of the lake was filled and the tailings formed a beach well above the lake surface. In 1932 the mine decided to reclaim this area. Large amounts of black muck were haul onto the tailings and worked into it. The area was the fertilized and seeded with a clover and Timothy mixture. Trees, willows and poplars, were then planted. The success of this site as with similar early reclamation efforts, for example Hollinger Park in Timmins and the Coppercliff part Sudbury, are a credit to the industry.

During the late 1960's and early 1970's a concerted effort was made by the various companies now under the control of Pamour Porcupine Mines Ltd to reclaim their tailings disposal areas.

As a result of the variability in the success rate, Pamour Porcupine Mines Ltd requested the assistance of the Horne-Guelph program. A total of 33 samples from the 15 tailings disposal areas were tested. While the majority showed acceptable growth with no ph amendments, high fertilizer rate and a simple forage crop seed mixture, the five acidic samples did not respond to similar conditions.

The test work on the five samples indicated that:

- a) On the Delnite sample, "Trap shoot dam", only a marginal growth rate was recorded when amended with agricultural limestone up a rate of 60 tons per acre.
- b) The Aunor slope site indicated acceptable growth of Creeping Red Fescue with rates of 60 tons per acre of agricultural limestone but very poor growth amendment ratio resulted in erratic to poor growth result.
- c) Even when amended with 60 tons per acre of agricultural limestone, two of the three acidic Schumacher samples achieved excellent growth at 10 tons per acre.

Due to the poor results achieved in the growth room at Guelph direct seeding of the acidic areas at this time seems hazardous at best. If direct seeding is contemplated further research is advised. However due to the small area involved at two of the dams and the abundance of non-reactive gold tailings nearby I would suggest that the areas just be covered with the latter. Even concerning the large Schumacher acidic tailings disposal area covering with a silicious tailings overburden should be considered. This may involve a review of the Schumacher tailings disposal management.

1980

An area of 40.5 acres of dam slopes were graded and seeded. This revegetation which was done by a contractor was successful.

1983

Some 76 acres were seeded by contractor in June, mostly on top of the dam plus a small amount on shoulders. 51 percent had to be covered by mulch in a 1982 make work program. Some areas were seeded in October under warranty. The seed/fertilizer mix for both years was: fertilizer 5-20-20, 1500 lb/acre; Red Fescue total 20130 lb/acre;

APPENDIX B

General Notes for Fertilization, Mechanical Seeding and Hydromulching

Fertilizer, seed and mulch application should take place as early as possible in the spring. The date should be determined according to local climate and soil conditions. In Northwest Québec this should not occur after June 30th in any one year.

The contractor or company personnel should not carry out work under adverse weather conditions such as high wind, frozen ground or ground covered with snow, ice or standing water, or heavy rain storms.

If work is done by a contractor he should be able to guarantee his workmanship, the service specified and the quality of the materials. Should any of the above be found to be at fault, the contractor will correct the error at no extra cost. The contractor should not be held responsible for growth failure if its a result of an act of God such as abnormal or adverse weather conditions.

1) Fertilizer

a) Pre-application

The sulphide tailings will generally require a pH modifier or an overburden layer applied prior to the fertilizer application. If a pH modifier such as agricultural limestone is to be used it should be spread several days before the fertilizer is applied. Once it has been spread the modifier should be cultivated using either a disc, a rotovator or in the case of steep slopes with a clod-buster to a depth of 4 to 6 inches.

Even if no pH modifier has been used it is generally a good practice to cultivate the entire area, especially with a rotovator. This will level out any uneven surfaces and thus reduce any ponding of water after a rain storm. It will also present a more homogeneous soil condition.

b) Application

The fertilizer should be analyzed as specified in the schedule of materials. It should be in a granular form, dry, free flowing and free of lumps. The fertilizer can either be shipped in bags, labelled to indicate weight and analysis, or in bulk shipment. It should be noted that if the amount of fertilizer is of sufficient quantity the supplier will custom blend the fertilizer. The supplier will also remove the filler from the fertilizer. At times the filler is more than half the weight of the fertilizer composition. This will result in a saving in freight costs.

If the fertilizer is to be stored prior to use the method used should ensure that it is secure from the elements especially precipitation.

The area should be fertilized with the full amount as required. Most use a multi-directional broadcaster as the mechanism to spread the fertilizer. After fertilizer application some incorporate it by discing to a depth of 4 inches. The method preferred by the Horne Division of Noranda Mines Ltd. is to work the area with a cultipacker with a spike-toothed harrow attached. This works the fertilizer into the soil up to 1 to 2 inches and produces a well packed seedbed.

2) Seeding

a) Bed preparation

After incorporation of fertilizer but prior to seeding, the area to be vegetated should be cultipacked. This ensures a packed, firm seed bed which through experience has been shown to be the most ideal condition for seeding. Light fluffy seed beds have a tendency to bury the seed too deep and inhibit germination. As stated previously the Horne Division likes to incorporate the procedure fertilizer incorporation with seed bed preparation. One thing found out by Inco and ourselves is that the less time you work the sulphide tailings the more successful the germination and the more luxurious the growth.

b) Seed and Inoculant

The grass and legume seed which used singly or in a mixture should be Canada No. 1 seed as specified. It is supplied in bags which are labelled to indicate species content, grade and weight. It is recommended that when possible only pedigree seeds be purchased. The need for this requirement has been found to be especially critical when purchasing legumes. Legumes require to be inoculated prior to seeding. The inoculant should be of the type specifically adapted for the legume being used in seeding and contain sufficient viable bacteria to ensure inoculation.

The quality of the inoculant is critical. For this reason, inoculant should be obtained only from commercial seed companies as they are aware of the need for controlled storage conditions for inoculant prior to sale. After the inoculant has been obtained, it should be stored in a refrigerator or a very cool room until time to use. When the inoculant is taken into the field at time of seeding, it is important that these cool conditions be maintained as closely as possible. The use of a styrofoam cooler chest or equivalent containing ice packs is strongly recommended for storing the inoculant in the field. Note, never leave packages of inoculant lying in a closed vehicle during the hot weather or exposed to direct sunlight. Always keep in the shade. Opened packages may be kept for several days provided cool storage conditions are maintained. Never use inoculant after the expiry date printed on the package has gone by. Doubling or tripling the amount after the expiry date has been exceeded has no effect whatsoever.

c) Seed application

Seeding of all areas should take place within 48 hours of cultipacking, unless weather conditions prohibit, which in the case of a heavy rainfall, the whole area should be very lightly scarified to remove any surface crusting.

Seed can be applied by using a packer type seeder, a seed drill or a hydroseeder. The most preferred method is using the packer type of which the Brillion seeder is the most commonly used. This seeder has two sets of rollers. The first set opens a small farrow as well as firming the seed bed. The seed is dropped between

the two rollers at a preset rate. If a mixture of grasses and legumes are used a double compartment seed box is required. It should be noted that when the seed mixture calls for a legume it must not be inoculated by mixing dry inoculant with the seed in the seed box. The legume should be inoculated by the "wet" method prior to placing it in the seed box. It is possible to calibrate each seed box feeding system to ensure the correct amounts are applied. The second set of rollers is off-set so that it covers the sower seed to a depth of $1/8 - 1/4$ inches. It also firms up the seed bed and produces minute furrows to retain some moisture.

Brillion seeding is usually accompanied but not always with a hydromulch. If light amounts of fertilizer are being applied they can also be mixed and spread with the hydroseeder. If the mixture to be hydroseeded includes a legume the rate of use of inoculant should be not less than 4 times the normal recommended rate for mechanical seeding. Inoculant viability and attachment to seed is drastically reduced when hydroseeding. The increase in rate compensates for viability loss and ensures sufficient concentration of bacteria on the seed coat. Inoculant viability and attachment to seed is drastically reduced when hydroseeding. The increase in rate compensates for viability loss and ensures sufficient concentration of bacteria on the seed coat.

The water used should be adequate for creating an homogenous solution. If a mulch is used sufficient water must be used so that when the mulch slurry is discharged from the nozzle, it will disperse easily and not in lumpy aggregates. The water used for hydraulic seeding should be free of all impurities, such as metals, organics, sediments, which would adversely affect growth. After the hydraulic mulcher has been charged no other water or material should be added to the mixture. The mixture shall be dispersed within 30 minutes of charging being completed. If the inoculant seed and fertilizer are contained for too long a period then either or all of the following may occur:

- i) the inoculant viability may be affected by the fertilizer;
- ii) the fertilizer may become saturated and dispersed;
- iii) the seed may absorb sufficient water to cause pre-germination.

The method of seed application preferred by the Horne Division is brillion seeding followed by a hydraulic mulch. The mechanical seeder is superior to the hydroseeder. While the use of a mulch provides a protective cover for the seed prior to germination.

3) Mulch

Mulches are applied to the tailings as a temporary stabilizer. A mulch usually provides three major benefits:

- i) erosion control - stabilize the soil against water and wind erosion, reduce the impact of precipitation, prevent the fine soil particles from sealing the surface against water penetration;
- ii) temperature control - insulates the soil surface to protect the young seedlings;
- iii) moisture control - forms a barrier to moisture loss and maintains consistency for the benefit of germination and initial growth of the seed.

Also if the mulch is organic in nature, it will supply needed organic mater and help promote micro-organism buildup in the tailings. Mulches usually fall into three types.

a) Hydraulic (Fibers) Mulch

Most products are produced by grinding materials such as raw wood, wood cellulose, newsprint and form of dried plant materials. They can be found under a variety of names such as "Conweb", "Silvafibre", "Verdyol", "Hollow Form", etc. The material is sprayed uniformly over the area using a hydroseeder. The mulch can be added directly to the hydroseeding slurry or applied after the seeding operation. It is this latter technique which is preferred by the Horne Division. The fiber mulch can be either by itself in a water slurry or with a chemical binder if erosion conditions warrent it.

The Ontario Ministry of Transportation⁽¹⁰⁾ defines the hydraulic mulches into types "A", "B" and "C". Each must be capable of forming a homogeneous slurry and remain in that state with agitation. It must contain no growth or germination inhibiting factors and be free of all noxious weeds.

- i) Type "A" - consists of raw wood fibre produced from clear, whole, hardwood chips and it is usually dyed green.
- ii) Type "B" - consists of a mixture of shredded newsprint, raw cotton fibre and straw processed to produce fiber lengths of 15 mm minimum and 25 mm maximum. The greater proportion of the ingredients is straw. This is the type hydraulic mulch used by Inco, Pamour Porcupine Mines, and the Horne Division of Noranda Mines.
- iii) Type "C" - consists of finely ground cellulose pulp derived from recycled newsprint and it is usually dyed green.

The rates of hydromulch vary from 500 to 3000 pounds per acre. The rate of 500 pounds to 1500 gallons of water is suggested. This will result in an uniform dispersion and if the seed is being applied at the same time the seed will be protected as it passes through the centrifugal pump commonly used in hydraulic seeders.

b) Straw Mulch

Most people believe that the straw mulch is superior to the manufactured hydraulic mulch. It is the most common type of mulch used in North America today. Unfortunately most tailings disposal areas are situated in areas far away from the supply. With changes in agricultural practices, for example, stubble mulching, discing in grain straw after harvest and the use of shorter straw grain varieties, straw has become increasingly more difficult to procure. Hay is not commonly used because it is very likely to contain weed seeds, disease organisms or undesirable insects, all of which may interfere with the seedling establishment and growth. Hay also presents a mechanical problem in that the bales are compressed so tightly that the equipment has difficulty in applying it.

Although straw mulch can be spread by hand on small areas or areas inaccessible to equipment it is usually applied by a mulch blower which is capable of applying straw and emulsified asphalt tackifier simultaneously. Without chopping it into shorter lengths the mulch blower separates the straw from the bales and applies the mulch in a uniform, cohesive mat. The mat usually is between 25 and 50 mm in depth. A straw mulch is capable of spreading slightly over 100 tons per day and can distribute it up to 75 feet in all directions.

The straw can be held in place by incorporating it into the upper layer of the tailings by discing or crimping as well using a chemical tackifier as previously mentioned.

c) Organic Mulch

Organic mulches such as manure, sewage sludge are rarely applied to a tailings disposal area due to their remote location. Since high rates of these amendments must be applied the transportation costs are inhibitive.

d) Constraints

As previously noted when discussing seeding the application of mulch should not be carried out under adverse conditions, of high winds above 20 mph, frozen ground or ground covered with snow, ice or standing water. It can be sprayed during a light rain although this is not advisable. The Ontario Ministry of Transportation⁽¹⁰⁾ puts the following time constraints on its seeding and mulching programs.

TIME CONSTRAINTS BY MTC DISTRICT			
SEEDING AND MULCHING	SOUTHERN ONTARIO	MID-ONTARIO	NORTHERN ONTARIO
	MTC DISTRICTS	MTC DISTRICTS	MTC DISTRICTS
	Chatham London Hamilton	Stratford Owen Sound Toronto Port Hope Kingston Ottawa	Bancroft Huntsville North Bay New Liskeard Cochrane Sudbury S.S. Marie Thunder Bay Kenora
Seeding with Straw Mulch or Hydraulic Mulch Types A, B, or C.	Spring start-up to June 14 AND Aug. 16 to Sept. 30.	Spring start-up to June 14 AND Aug. 1 to Sept. 30.	Spring start-up to June 14 AND Aug. 1 to Aug. 31
Seeding with Straw Mulch only	June 15 to Aug. 15 AND Oct. 1 to Nov. 15	June 15 to July 31 AND Oct. 1 to Oct. 31	June 15 to July 31 AND Sept. 1 to Oct. 15
Seeding Cut-off Date	Nov. 15	Oct. 31	Oct. 15

Although the Ministry discontinues the use of hydraulic mulches after June 14th in its northern districts the Horne Division has had great success using them up to July 7th. After this date the chances of success would be reduced due to stress experienced by the young seedling as a result of the high temperatures and the lack of sufficient moisture. During July and August the evapotranspiration normally greatly exceeds the rainfall.

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Compliments of Falconbridge Nickel Mines Limited



**How to Establish Vegetation
on High Iron-Sulphur Mine Tailings**

by

R. E. Michelutti

Reprint from Canadian Mining Journal.



How to establish vegetation on

By R. MICHELUTTI
Falconbridge Nickel Mines

The ore in the Sudbury Basin consists of a number of sulphide minerals composed predominantly of nickel, copper and iron with various other minor but valuable elements. To separate the valuable minerals from the gangue, the ore is crushed and ground to at least a fineness of 100% - 48 mesh. The copper-nickel sulphide minerals are separated from the gangue minerals by a combination of flotation and wet magnetic separation processes.

Three products result - a copper-nickel concentrate that is sent on for further processing, a pyrrhotite (iron-sulphide) concentrate that is either stockpiled or disposed of, and the tailings. Although consisting predominantly of silicate minerals, the tailings do contain minor amounts of sulphide minerals and a typical analysis will show about 0.85% sulphur. The pyrrhotite concentrate contains about 36.5% sulphur and 56.0% iron.

The relatively coarse tailings fraction, above 25 microns, amounting to about 70% of the total is separated by cycloning and returned to the mine for backfill. The fine tailings or tailings slimes, generally minus 25 microns in size, is discarded, either separately or mixed with the pyrrhotite, to tailings disposal sites.

A ton of average grade Sudbury ore

produces 200 lbs of concentrate, 800 lbs of tailings backfill, 500 lbs of pyrrhotite and 500 lbs of tailings slimes. Thus, half of the ore mined consists of waste products that may be disposed of on surface. If possible, land-locked basins or lakes are selected as tailings disposal sites, but if such natural depressions are unavailable the tailings slimes must be contained behind artificial dams.

Falconbridge Nickel mines over 4 million tons of ore annually and therefore each year has to dispose of some 2 million tons of tailings slimes and pyrrhotite, which occupy a volume of over 35 million cubic feet.

Seepage

When a tailings disposal area reaches its designed capacity and is abandoned there are liable to be three major problem areas, acidic seepage or run off, dust and aesthetic appeal. A properly designed and maintained tailings disposal area will minimize the problem of acidic seepage and run off, however, it is unlikely that it can be completely eliminated.

The material constituting tailings is by its very nature a dust, and large areas denuded of vegetation may be picturesque in some locations on our planet but they cannot be considered as attractive features on the wooded landscapes of north-central Canada.

During the life of the tailings pond,

water is continually seeping through it and becoming contaminated with iron and various metal sulphates. Because of the fine particulate nature of the tailings, the constituent minerals present a tremendous surface area, making them extremely susceptible to leaching and other chemical reactions.

Where sulphide minerals are present, sulphuric acid is generated, and depending on the amount of sulphides and the composition of the gangue minerals, the pH of the seepage effluent may be in the order of 3.0 or lower and if the volume is sufficient the downstream ecological environment may be seriously endangered.

Dust storms

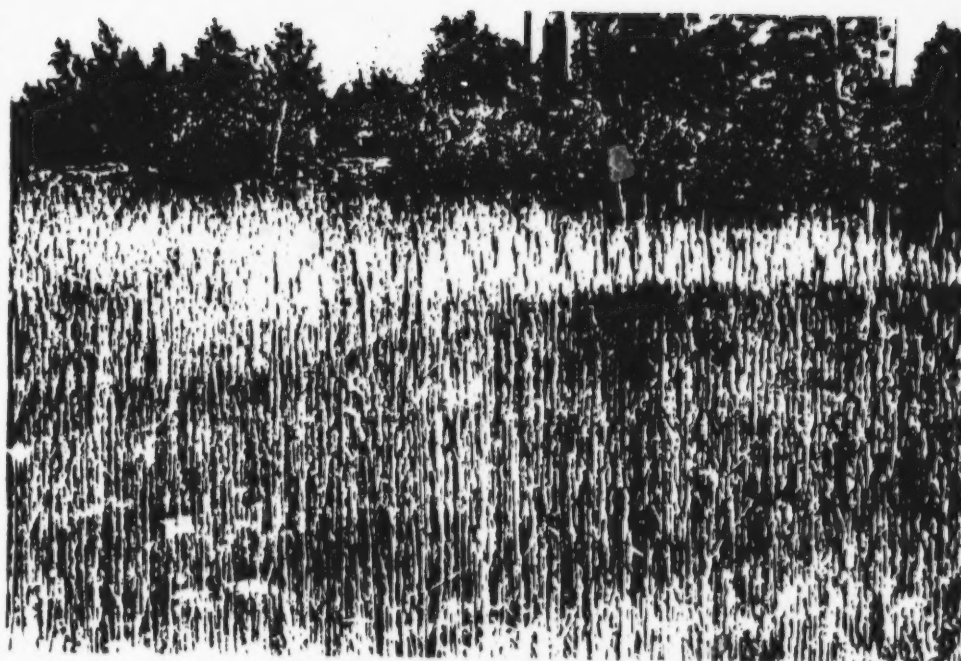
Once a tailings pond has dried up, the fine particles easily become wind-borne. This, coupled with the flat topography of tailings areas, results in severe dust storms, even at moderate wind velocities. Since the dust contains metallic salts and is easily dispersed throughout the adjoining area, widespread contamination of a watershed may result.

If residential areas or manufacturing industries are located nearby, the dust will present both a serious nuisance and increased problems and costs in the maintenance of machinery and equipment.

Although mining operations are usually located in remote areas, this is not



1971



1972

High iron-sulphur mine tailings

always the case, and even so, with our increasing awareness of the necessity to preserve wilderness areas for recreational purposes, the past practice of merely abandoning tailings areas without any attempt to restore them to their natural state is no longer acceptable.

Stabilization of tailings

Abandoned tailings areas must be stabilized to reduce or eliminate the problems previously mentioned. Various methods have been employed to reduce these problems, but most fail to eliminate all of the problems. Dust problems, for example, may be solved by placing an overburden of crushed slag, rocks or gravel on the tailings. This will not, however, reduce seepage or improve the appearance of the area.

Water cover

Another method is to completely cover the tailings area with water. Provided that dams are properly constructed to stop seepage this method will solve all three problems. The only disadvantage is that the area must always be maintained to ensure that dams won't fail and that the water cover remains. Once a mining complex becomes inoperative maintenance will normally cease and it is only under particular circumstances that this method could be acceptable.

Other methods, such as chemical

stabilization with asphalt or polymers to produce a layer impervious to both air and water, also have the disadvantage of requiring maintenance. Furthermore, with this type of cover, the aesthetic quality of the area is hardly likely to be improved.

The obvious solution to the problem, if it can be achieved, is to restore the terrain to some reasonable semblance of its natural state by providing a cover of vegetation over the tailings. This method restores the aesthetic value and may even improve on the intrinsic value of the property.

Revegetation prevents the material from becoming windborne and will restrict, even though it may not entirely eliminate seepage. Also, with time, the endemic species will encroach to make the area self-sustaining.

The establishment of vegetation on tailings, unfortunately, is not a simple task, for the following reasons:

- Tailings are unsuitable as a soil for supporting plant life for a number of reasons. The material has a poor structure lacking in aggregates. Tailings are almost entirely deficient in nutrients and in an ion exchange capacity. Proper bacterial communities are absent, and toxic concentrations of heavy metals may be present.

- Because of the extremely fine particulate nature of the tailings, de-watering takes a long time and the area remains an inaccessible bog long after

the surface has dried. Specialized machinery may therefore be needed to attempt the revegetation operation.

- Since the areas are large flat expanses composed of very fine particles, dust storms are common and for this reason it is essential that the entire tailings area be stabilized at one time. Otherwise established vegetation can easily be destroyed by sandblasting or burial by the unstabilized material. If it is not practical to vegetate an entire tailings area at one time it will be necessary to provide some form of temporary stabilization to the unvegetated portion.

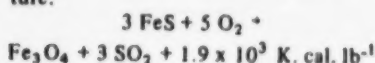
Nickel Rim mine tailings

Nickel Rim Mines operated a mine and concentrator between 1952 and 1958 on a property located at the east end of the Sudbury Basin approximately 7 miles north of the town of Falconbridge. During these years, some 35 acres of land were covered with tailings.

In the Nickel Rim concentrator operation, no attempt was made to recover pyrrhotite which was discarded with the tailings. Neither was any tailings used for mine back fill at this operation so the material discarded consisted of approximately two-thirds silicate gangue minerals and one-third pyrrhotite.

Although the silicate gangue is inert the pyrrhotite is highly reactive (81

times more so than pyrite), and under certain conditions spontaneous combustion will occur at room temperature.

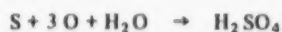
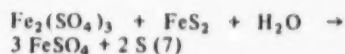


Even when mixed with tailings the heat produced by the oxidation of the pyrrhotite, where any segregation has occurred, will be sufficient to prevent the growth of any vegetation.

The present surface of the Nickel Rim tailings, from 1 in. to 5 ft in thickness, is a reddish brown colored mass of hydrated iron oxides. Greater than average concentrations of iron and sulphur are present in this oxidized surface layer because of capillary action which brings dilute salt solutions from the interior of the tailings mass to the surface. Subsequent loss of moisture at the surface due to evaporation results in a build up of metallic salts. (Table 1)

The iron and sulphur accumulating at the surface produces a complex matrix known as a "ferruginous cap". This ferruginous cap may become as hard as concrete and virtually impossible to vegetate.

Another barrier to overcome in establishing vegetation on tailings which contain pyrrhotite is the production of sulphuric acid. Polythionates reacting with ferric sulphide result in the production of sulphuric acid which lowers the pH in the oxidized layer (Table 1) to values that are intolerable to any form of vegetation.



In 1964 Falconbridge purchased the Nickel Rim property to acquire the considerable amount of low grade ore that had not been mined. At the time pollution was not a serious concern but with changing conditions, Falconbridge subsequently became aware that it had not only purchased some low grade ore but also a pollution problem of considerable proportions.

Unique problem

Although the techniques for establishing vegetation on tailings piles of silicate minerals were well known, nothing had ever been done with the high sulphur content (pyrrhotite) tailings such as those at Nickel Rim. Falconbridge, therefore, found it necessary to embark on a research program with the objective of determining whether the establishment of a permanent cover of vegetation could

be accomplished economically on this type of tailings.

This report is a summary of the research work performed by Falconbridge to date in its attempts to vegetate this troublesome area.

Research summary

Research on the vegetation of acid mine tailings commenced September 1970 by the Industrial Wastes Control Department at Falconbridge. Initial tests were conducted in a growth chamber to determine first of all whether plant life could be made to grow at all on oxidized high iron-sulphur and acidic mine tailings. The most economical neutralizing agent and fertilizer requirements had to be determined as well as the plant species that are best adapted to this environment.

Because of limited space in the growth chamber only one or two parameters could be investigated during each test.

TABLE 1 — ANALYSIS OF NICKEL RIM TAILINGS

	Upper Oxidized Layer	Lower Unoxidized Layer
Magnesium	4.25 %	6.4 %
Sodium	.16 %	1.64 %
Potassium	.41 %	.74 %
Calcium	4.44 %	5.53 %
Aluminum	2.3 %	3.2 %
Sulphur	6.23 %	2.31 %
Nickel	.05 %	.220 %
Copper	.031%	.063 %
Zinc	.003%	.0128%
Cobalt	.041%	.03 %
Iron	27.9 %	12.7 %
pH	3.0	4.5

Since any solution to the problem had to be economically viable, it was fundamental that in conducting the experiments the materials utilized would be locally available at a reasonable cost.

Neutralization

The initial series of experiments was set up by Fedko and Michelutti (1) to determine whether the acidity of the tailings could be neutralized by the application of agricultural limestone (CaCO_3) and/or lime (CaOH) and also whether a commercial grade fertilizer (10-10-10) would provide the nutrients required to sustain plant growth.

Slightly acidic alluvial sand from the Falconbridge area served as a control. Plant species for these tests were chosen from varieties suited to local climatic conditions and on proven ability to withstand acidity and drought, as well as their availability.

From these preliminary tests it was quite apparent that lime and/or limestone were essential for plant growth on acid tailings. The more agricultural limestone or lime applied to the tailings, the greater the plants' longevity, (Fig. 1).

In the initial experiment all plants died within 30 days but the length of survival was directly related to the amount of neutralizing agent provided. Since both lime and limestone produced similar results on plant vigor and longevity, the lime was discontinued because of its corrosive nature and its potential to produce a toxic alkaline soil by over liming.

No conclusions as to the suitability of the fertilizer utilized in the experiment could be drawn since all the plants died because of insufficient neutralizing agent. However, the control sand pots did indicate the best application rate for 10-10-10 fertilizer to be 1/2 ton per acre.

Optimizing limestone

Having determined that limestone was essential, a second set of experiments was designed and undertaken to determine just how much would be required to ensure plant survival. For these tests the fertilizer content was maintained constant at 1/2 ton per acre.

In January 1971, Hulley set out to determine the appropriate limestone requirements for Nickel Rim mine tailings. Besides limestone content, the advisability of using a straw-asphalt mulch cover was also tested. Although the duration of the test was restricted to a two month period, positive results were achieved as all plants survived during this period.

It was determined that for the Nickel Rim tailings an initial dosage of 10 tons of limestone per acre would be required. The test also showed that a straw mulch cover resulted in greater yields than no cover on both the sand control pots and the tailings pots, with all other conditions being equal. (Fig. 2)

Now that the appropriate limestone content had been determined and it had been shown that a mulch cover of straw-asphalt was beneficial, it was decided that the next step should be to perform experiments in the field to test the validity of the laboratory results.

In May 1971, Langford set up field tests using a randomized block design. Test plots were established on alluvial sand, inactive low iron-sulphide Falconbridge tailings (12% Fe, 1% S), and Nickel Rim mine tailings. The alluvial sand and Falconbridge tailings were to act as controls. Unfortunately the test plots on the Falconbridge tailings were mostly covered and destroyed by

blowing dust in a matter of only two weeks time.

So that there would be a basis of comparison with the lab tests the fertilizer (10-10-10) was still maintained at 1/2 ton/acre on all the plots. The agricultural limestone (not more than 40% + 100 mesh), was applied at 10 tons per acre on both tailings areas and at 4 tons per acre on the alluvial sand. These tests were, therefore, an attempt to duplicate in the field what was felt to be the proper fertilizer and limestone application, based on the laboratory tests.

Because of the success obtained in the growth chamber with a mulch cover, it was also decided to test various mulches in the field. The mulches tested were: straw-asphalt, curasol (a polymer dispersion material), and a 2 in. soil cover. At the same time, 16 different grass and legume species were tested, in a block design, under each mulch cover. Data accumulated between May and October was analysed by Langford (3) in March 1972, with the following conclusions.

- The plant species best suited to the acidic tailings were: fall rye, bromegrass, red top, colonial bentgrass, creeping red fescue, sheep fescue, sweet clover, alfalfa and white clover.
- The mulch covers all proved to be superior to no cover.
- The greatest differences in mulch covers appeared in the test plots on the Nickel Rim tailings where a 2 in. soil cover resulted in a healthy vegetation growth compared to the other plots on these tailings where the growth was stunted and had a high mortality rate. The exact reason why this plot was successful it still not known since the soil became very acidic with a pH of 3.5 in the space of a months time. Perhaps the soil contains a greater ion exchange capacity,

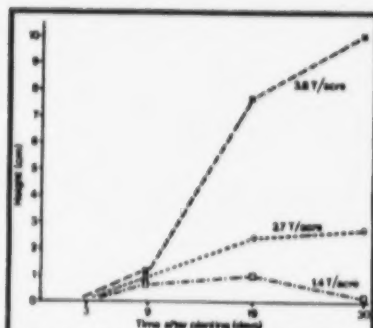


Fig. 1 Effect of limestone on Timothy in tailings

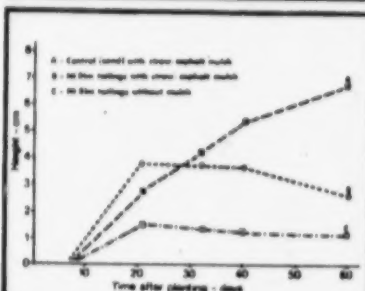


Fig. 2 Effect of straw asphalt mulch on legumes

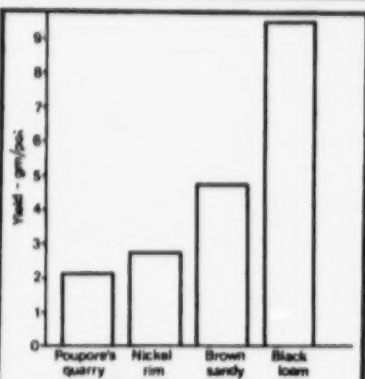


Fig. 3 Comparison of topsoils

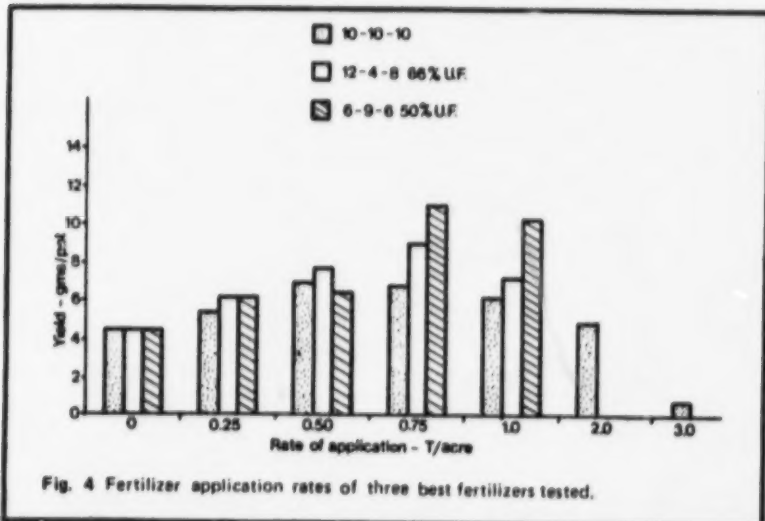


Fig. 4 Fertilizer application rates of three best fertilizers tested.

beneficial microorganisms, or the micronutrients required by the plants which the fertilizer does not provide. Root studies the following year showed that the roots tended to fan out a great deal in the soil cover before eventually penetrating the tailings. Perhaps this soil cover helps to establish the young plants when they are most susceptible to adverse conditions and upon maturing their root systems are then able to invade the inhospitable high iron sulphur tailings.

• The physical grade of the limestone is very important in affecting a pH change since it must be solubilized to be effective. In one test plot that was treated with 50 tons/acre of a coarse limestone (80% + 10 mesh) compared to the finer grade (60% - 100 mesh) normally used, the seeds all failed to germinate. Even after a six month observation period, there was no growth on this particular test plot.

The results of this initial field test work with the Nickel Rim tailings gave some hope that vegetation could not only be established but also maintained on this type of highly oxidized acidic tailings.

The next series of tests by Gaylor (4) set out to determine the best locally available soils for use as a cover and the optimum thickness of application. The soils were spread in 1 in., 2 in., 4 in. and 6 in. layers and not mixed at all with the underlying tailings. This was done in an attempt to reduce metallic salt concentration at the surface by applying soils having a lesser capillarity rate than the tailings.

Four locally available soils ranging from sand to loam were selected for testing in the growth chamber. 10 T/acre of limestone with 1/2 T/acre of fertilizer was applied on top of the soils. After two months, yields were determined and black loam at a 6 in. depth proved to be superior to the other soils. Even a 1 in. to 2 in. layer of black loam showed a definite improvement in plant growth over any of the other soils. (Fig. 3).

Tests conducted by Cyr (5) on soil properties had demonstrated that a loamy soil has a lower capillarity rate than sandy soils. This, coupled with the fact that black loam has a greater cation exchange capacity (8), could account for the increased yield.

A significant result was that the legumes did far better in these tests than any previous growth chamber tests, and appeared healthier than the grasses for the first time. A good legume catch is very significant in establishing vegetation over long periods of time because of their ability to fix atmospheric nitrogen in the soil.

Fertilizer types

Up until this time, the fertilizer used

had been exclusively 10-10-10 N-P-K because it was readily available. Cyr (5), therefore, set out to determine whether there might be a better fertilizer to use for establishing vegetation.

Fig. 5



Five fertilizers were studied: CIL 10-10-10, CIL 6-9-6 50% U.F., CIL 12-4-8 66% U.F., CIL 15-5-10 40% U.F. and CIL 2-1-2 sheep manure.

The slow release fertilizer, 6-9-6 50% urea formaldehyde, performed the best at 3/4 T/acre (Fig. 4). The original 10-10-10 at 1/2 T/acre produced much lower yields during the 10-week duration of the experiment and over a longer period of time might have shown even greater differences. A significant observation, as shown in Fig. 4, is that an excess of fertilizer stunts plant growth and is more harmful than no fertilizer at all.

This situation has been termed physiological drought and exists when water is plentiful but a greater osmotic pressure results in the soil because of the high salt content compared to the plants roots. Water will then leave the plants to reduce the pressure gradient created and in this way the plants dehydrate. As previously mentioned, legumes are important as soil enrichment agents, and once properly established the fertilizer requirements may then be substantially reduced.

The field plots set up by Langford during May 1971, were examined by Johnston (6), Oct. 1972, for legume root nodules (Fig. 5). Preliminary observations showed that alfalfa has more nitrogen nodules than sweet clover and that legumes growing in the 2 in. soil cover have much better nodulation than legumes growing directly in the tailings.

The plants on the soil cover had most of their root structure fanning out in the soil with portions penetrating down into the tailings. Most of the nodulation in these plants occurred in the upper root zone growing in the soil cover. This is probably attributable to a proper bacterial ecology in the soil cover, especially the nitrogen producing bacteria, nitrosomonas and nitrobacter which oxidize ammonia to nitrate.

Even though good nodulation was observed in some plants, none had the characteristic healthy pink coloration. The pink coloration is hemoglobin produced symbiotically by the bacteria and legume. More tests are therefore necessary to determine if these nodules are adequate for soil enrichment or if healthier nodulation can be induced by inoculation with the appropriate bacteria. Tests are now under way to determine the effects of inoculation on legumes.

From all the data accumulated over the past two years, some basic conclusions can be made at this time on the vegetative stabilization of the acidic high iron-sulphur tailings at Nickel Rim.

Conclusions

- The tailings area should be first covered with a 4-6 in. layer of the best locally available soil. If this soil is low in organic content, it should be supplemented with sewage sludge, manure or loam. This should reduce the rate of salt build-up at the surface as well as increase the cation exchange capacity.
- High grade fine pulverized agricultural limestone (60%-100 mesh) at 10 T/acre should then be applied to the soil cover.
- 6-9-6 50% U.F. fertilizer should then be applied at a rate of 3/4 T/acre. The slow release factor of the fertilizer will help sustain the plants for the maximum possible period of time without maintenance. Instant release fertilizers can dissolve and wash away during periods of heavy rain fall and may therefore be largely wasted.

- The seed mixture to be used on these tailings is: fall rye, brome grass, red top, colonial, bentgrass, creeping red fescue, sheep fescue, sweet clover, purple alfalfa, and white clover. For all the test plots rye was maintained at 60 lbs/acre and the other seeds were applied at a combined total of 90 lbs/acre.

- Finally, a mulch cover of straw is extremely beneficial in protecting the young seedlings. This will however, greatly increase the cost, and further work is necessary to determine whether the extra expense is justified.

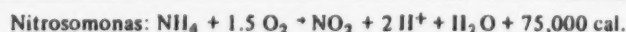
The research performed to date has resulted in a far better understanding of the problem of establishing vegetation on highly acidic iron-sulphur tailings. The effectiveness of this method in establishing a permanent cover of vegetation that will require little or no continuing maintenance has still to be determined. Also to be determined is whether a cover of vegetation will reduce the seepage from the tailings areas sufficiently to prevent or reduce to acceptable proportions the contaminants that get into the adjacent surface drainage systems. Only by continuing lab and field test programs may it become possible to find answers to the particular questions and problems which arise when attempting to vegetate troublesome areas.

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CANADIAN LAND RECLAMATION ASSOCIATION

**PROCEEDINGS
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THE ESTABLISHMENT OF VEGETATION ON HIGH IRON-SULPHUR MINE TAILINGS
BY USE OF AN OVERBURDEN

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ABSTRACT

Since 1971 numerous tests have been conducted at Falconbridge Nickel Mines Limited to establish vegetation on tailings containing high percentages of pyrrhotite.

The object was to produce a self-sustaining vegetative cover which would reduce or eliminate seepage long after the operations cease. This solution was not a simple task, however, due to the low pH (3.0), the heavy metal toxicity and the hard pan produced by the pyrrhotite.

Vegetation research, mainly on Nickel Rim Mine tailings, led to the use of overburdens as the most promising method of achieving the primary objective of a maintenance-free vegetative cover. The ideal overburden was found to be three inches of coarse material (1/4 inch) overlain with three inches of loam. The coarse material prevents the upward leaching of solubilized metallic salts, while the loam provides a suitable growth media for the plants.

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Introduction

The sulphide ores of the Sudbury Basin contain economic quantities of nickel, copper and iron, which occur mainly in the minerals pentlandite, chalcopyrite and pyrrhotite respectively. These valuable minerals are associated with a variety of igneous silicate host rocks.

In order to separate the metallic minerals from the waste host rock, the ore must be crushed and ground to at least minus 65 mesh. Separation is effected by the process of flotation and wet magnetic separation. One ton of average grade Sudbury ore, once processed, results in the following products:

1. 250 lbs. of copper-nickel concentrate
2. 500 lbs. of pyrrhotite (iron-sulphide concentrate)
3. 900 lbs. of coarse tailings (+25 microns)
4. 350 lbs. of tailings slimes (-25 microns)

The tailings are classified by hydrocyclones to produce a coarse fraction (70%) called sands and a fine fraction (30%) called slimes. The coarse fraction is returned to the mine as backfill and the slimes are discarded with the pyrrhotite. Falconbridge Nickel Mines Limited mines four million tons of ore annually which results in 1,800,000 tons of tailings slimes pyrrhotite, occupying a volume of 30 million cubic feet. This waste material is pumped as a slurry containing 15% solids, to landlocked basins or low lying areas called tailings ponds.

Here the solids are retained behind dams and the water is decanted off and treated prior to re-use or discard. Once these tailings ponds are full, however, they must be reclaimed, to eliminate or reduce pollution arising from them, as well as to improve the aesthetics of the area.

RECLAMATION PROBLEMS

The most acceptable method to date in reclaiming these tailings areas is by means of a vegetative cover. This, however, is no simple task for the following reasons:

1. The tailings acidify with time to pH 2.5 - 3.0
2. Heavy metal concentrations are high, especially upon acidification
3. The top 2 inches to 2 feet becomes rock hard due to a complex iron-sulphur matrix called a ferruginous cap
4. The tailings are devoid of nutrients and appropriate bacteria

EXPERIMENTAL WORK

(a) Fertilizers

Experiments were conducted in the laboratory and field with the objective of establishing a maintenance free vegetative cover that would revert back to nature. Of the fertilizers tested, 6-9-6 with 50% urea formaldehyde

allows the nitrogen to be released slowly and should therefore reduce or eliminate maintenance.

(b) Neutralizing Agents

From the laboratory tests, the minimum amount of limestone required to sustain plant growth over the 3-month test period was 10 tons per acre. The limestone used was "Beachville feed-grade" which has a 70% coarse fraction (sand particle size) and 30% fine fraction (dust size). This was chosen over other neutralizing materials for its ease of handling as well as for the coarse fraction which would act like a buffer and maintain a constant pH. In the field tests, however, the test plots acidified in 2-3 months' time to pH values ranging from 3.5 to 4.5. This was believed to be caused by the upward movement of sulphuric acid by capillary action during hot dry periods. The acid would also dissolve metallic salts and concentrate them upon evaporation on the surface. This was evidenced by white and yellow crystals (mainly Ca and Mg sulphates) on the surface of our tailings. It soon became apparent that continued maintenance would be necessary to maintain a vegetative cover on our tailings area.

(c) Overburdens

Due to the initial difficulties encountered with direct seeding in the tailings, tests with overburdens were begun in the laboratory and field. The overburdens used, ranging from gravel to black loam, had a pronounced effect in increasing yields, as well as allowing legumes to become established for the first time. Of the soils tested, black loam resulted in the greatest yields in the 3-4 month test period. However, there was some concern as to the long term effects. Due to the fine particle nature of the black loam it was felt that the upward movement of solubilized metallic salts would not be halted by the black loam and that after several years the concentrations would become toxic.

Dr. G. Courtin of Laurentian University was consulted and a decision was made to conduct research toward a master's thesis on this problem with Falconbridge Nickel Mines Limited personnel assisting with materials, assays and labour. Tony Spires, who was performing this work, came up with some basic conclusions. First of all, the black loam did result in the best initial growth of plants, but also had the highest heavy metal accumulation at the end of the experiment. The coarse sand and gravel overburden on the other hand acquired very little if any metallic salts, but growth was mediocre due to lack of moisture. The ideal overburden in these tests was a 3-inch layer of 1/4 inch crushed slag overlain with 3 inches of black loam. The slag broke up the capillary action and the black loam provided a growth medium with a good cation exchange capacity (128.5 me/100g) and moisture retention capability (137g/100g).

As with some of our earlier experiments, Mr. Spires demonstrated that a solid barrier between the tailings and 6-inch overburden resulted in zero to poor growth due to a lack of moisture.

REVEGETATION PROJECTS

(a) Nickel Rim Mine

Nickel Rim Mine is an abandoned mine which was purchased by Falconbridge Nickel Mines Limited in 1964. With the purchase of this property, Falconbridge then became responsible for the pollution originating from the tailings area, covering approximately 30 acres. These tailings are composed predominantly of siliceous gangue (66%) and pyrrhotite (34%) and had been exposed since 1958.

After several tests with various overburdens, the results were sufficiently successful that we proceeded to reclaim 20 acres by use of an overburden. The overburden material used was a sandy loam located within one mile of the site. The cost of this project is outlined below.

<u>Materials</u>	<u>Cost/Acre</u>
Limestone	\$180.00
Fertilizer	160.00
Seeds	90.00
6-inch Overburden (includes Labour)	660.00
Labour (liming, fertilizing and seeding)	100.00
Total	<u>\$1,190.00</u>

A test plot with similar overburden material has been monitored since 1973 for pH to determine if re-acidification is taking place. The initial pH in September 1973 was 7.4 and as of March 1975 was 6.6. No maintenance on the 20-acre area has been conducted since it was established in 1975.

(b) Hardy Pyrrhotite Stockpile

In the Onaping area, 30 miles northwest of Sudbury, pyrrhotite had been stockpiled for future reclamation and recovery of values. This resulted in severe reclamation problems since the pyrrhotite containing 56% iron and 36.5% sulphur had not been diluted with tailings (siliceous gangue) as in other areas.

Adjacent to the pyrrhotite stockpile, a sandy gravel overburden was being removed from an open pit operation. This material appeared suitable as overburden and a 6 foot deep cover was placed over the pyrrhotite stockpile at no cost to the reclamation project, due to the close proximity of the pit operation.

This 17-acre area was seeded with the use of conventional farm equipment at a cost of \$326.00 per acre in August 1973. There was some concern, however, that the sand-gravel overburden was so coarse that the nutrients would wash out faster than in a loamy sand overburden. To maintain a healthy vegetative stand an additional 300 pounds per acre of 12-18-12 40% sulphur coated urea fertilizer was applied during August of 1976 at a cost of \$150.00 per acre.

The vegetation is doing very well and numerous unidentified weeds as well as several tree species, including trembling aspen and birch, have already encroached.

(c) East Mine Tailings

The East Mine tailings should have been relatively easy to vegetate since pyrrhotite was not discharged in to this area. These tailings were seeded in 1969 without the use of any overburden and the resulting grass cover was poor. Large bare areas were scattered throughout, without any vegetation whatsoever. It soon became apparent that the tailings were not homogeneous and that these bare areas had a very high iron content and a pH of 2.5. Unknown to the reclamation group at that time was that high iron waste products had been dumped into this area. These bare patches were covered with gravel at a cost of \$404.00 per acre and re-seeded.

The vegetation cover initially was not very healthy and required annual maintenance for the first five years. This was possibly due to the proximity of the nearby smelter.

More recently, however, birdsfoot trefoil and alfalfa have begun to spread. Fertilizer requirements should be reduced since these legumes can produce their own nitrogen.

OBSERVATIONS

1. Tailings should be pumped over pyrrhotite stockpiles during the final stages of a tailings pond to eliminate the need for an overburden.
2. The use of domestic garbage, mine wastes, etc. as overburden materials should be investigated. This would result in one revegetation scheme for both the tailings and garbage.
3. Planning in conjunction with operating departments will save considerable dollars, e.g.- removal of overburden materials from open pits or dam construction, etc.
4. Finally, it should be kept in mind that continued monitoring of the vegetation is essential in order to determine the effectiveness of the overburden material in achieving a maintenance free vegetation cover.

CONCLUSIONS

Based on past and continuing research on tailing pond reclamation at Falconbridge Nickel Mines Limited since 1971, the following conclusions are reached:

1. Tailings areas containing high quantities of iron-sulphur and/or heavy metals can be vegetated successfully by use of an overburden material.

Conclusions (cont'd)

2. The ideal overburden should be coarse enough to reduce or eliminate upward leachate migration from the tailings while at the same time providing sufficient moisture retention and a cation exchange base for the vegetation.
3. Initial establishment costs by using overburdens are quite high but maintenance work is substantially reduced.

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